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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

In re Application of:	
Piero LOSI et al.	
	Group Art Unit: 1791
Application No.: 10/584,798	
	Examiner: Justin R. Fischer
Filed: April 18, 2007	
	Confirmation No.: 3422
For: PNEUMATIC TIRE AND PROCESS FOR ITS MANUFACTURE	

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Commissioner for Patents
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VIA EFS-WEB

Sir:

APPEAL BRIEF UNDER 37 C.F.R. § 41.37

This is an appeal to the Board of Patent Appeals and Interferences ("the Board") from the Final Office Action dated September 20, 2010 ("final Office Action"), finally rejecting claims 35-41 and 44-118 in association with the above-referenced patent application. A Notice of Appeal fee payment of $540.00 in accordance with 37 C.F.R. § 41.20(b)(2) was previously paid on March 21, 2011, upon the filing of a Notice of Appeal, and thus, this Appeal Brief is timely filed under 37 C.F.R. § 41.31 with a Petition requesting a two-month extension of time to extend the due date to July 21, 2011. In addition, payment of the Appeal Brief fee of $540.00 is submitted herewith via the EFS-WEB system.

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I. Real Party in Interest

The real party in interest is Pirelli Pneumatici S.p.A. (also known as Pirelli Tyre S.p.A.), the Assignee of the entire right, title, and interest in the application, as indicated by assignment of the present application duly recorded in the U.S. Patent and Trademark Office (USPTO) at Real 019206, Frame 0971, on April 18, 2007.

II. Related Appeals and Interferences

Appellant, Appellant's legal representatives, and Assignee are not aware of any appeals, interferences, or judicial proceedings that may be related to, directly affect, be directly affected by, or have a bearing on the Board's decision in this appeal.

III. **Status of Claims**

Claims 35-41 and 44-118 are pending in the application. Claims 1-34, 42, and 43 were previously canceled. Pending claims 35-41 and 44-118 were rejected in the final Office Action, and the rejections of those claims are at issue in this appeal.

The pending claims are set forth in the Claims Appendix.

IV. Status of Amendments

No amendments under 37 C.F.R. § 1.116 have been filed subsequent or in response to the final Office Action of September 20, 2010.

V. Summary of Claimed Subject Matter

A. Independent Claim 35

The subject matter set forth in independent claim 35 relates to a pneumatic tire 1 comprising a carcass structure 2 having at least one carcass ply 2a and at least one annular reinforcing structure 3 associated with said carcass ply 2a.[1] (Specification at p. 8, ll. 23-31; Fig. 1). The tire 1 further comprises a tread band 6 made of an elastomeric material at a radially outer position with respect to said carcass structure 2, a belt structure 5 interposed between said carcass structure 2 and said tread band 6, and a pair of axially opposite side walls 7 on said carcass structure 2. (Id. at p. 9, ll. 1-4; Fig. 1). The tread band 6 comprises: i) at least one radially extending first sector 9 substantially of a first elastomeric material; ii) a plurality of radially extending second sectors 10 positioned at axially opposite sides of said at least one first sector 9 and substantially of a second elastomeric material; and iii) at least one longitudinal groove 11 formed in said at least one first sector 9 and extending substantially for the entire circumferential development of the tread band 6, the at least one longitudinal groove 11 defining a cross section. (Id. at p. 9, ll. 10-19; Fig. 1). The first elastomeric material has a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of said second elastomeric material. (Id. at p. 9, ll. 24-28). The modulus of elasticity under compression at 23°C of said first elastomeric material is 20 to 80 MPa. (Id. at p. 9, l. 31, through p. 10, l. 2). A ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD

[1] The references to the specification in this Appeal Brief are merely intended to facilitate explaining how the originally-filed application provides exemplary embodiments and other exemplary disclosure relating to the claimed subject matter. Those references should not be construed as limiting the claims.

hardness at 23°C of the second elastomeric material is 1.15 to 2.70 (id. at p. 11, ll. 5-8), such that the cross section of the at least one longitudinal groove 11 remains substantially constant when a radially outer surface of the tread band 6 is in contact with the ground (id. at p. 11, ll. 9-12).

B. Independent Claim 53

The subject matter set forth in independent claim 53 relates to a process for building a pneumatic tire 1 comprising the steps of: a) building a carcass structure 2 having at least one carcass ply 2a associated with at least one annular reinforcing structure 3; b) assembling a belt structure 5 (Specification at p. 15, ll. 19-24; Figs. 1 and 6); c) arranging, at a radially outer position with respect to said belt structure 5, at least one radially extending first sector 9 of a tread band 6 (id. at p. 15, l. 25, through p. 16, l. 4), substantially of a first elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C of 20 to 80 MPa (id. at p. 16, ll. 21-25), the at least one radially extending first sector 9 defining a longitudinally extending groove 11 having a cross section (id. at p. 17, ll. 30-32); and d) arranging, at a radially outer position with respect to said belt structure 5, a plurality of radially extending second sectors 10 of the tread band 6, axially spaced apart and substantially of a second elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C lower than the value of the modulus of elasticity under compression at 23°C of said first elastomeric material. (Id. at p. 17, ll. 7-12). The steps c) and d) are carried out in such a way that said second sectors 10 are positioned at axially opposite sides of said at least one first sector 9, and a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the

second elastomeric material is 1.15 to 2.70 (id. at p. 11, ll. 5-8), such that the cross section of the at least one longitudinal groove 11 remains substantially constant when a radially outer surface of the tread band 6 is in contact with the ground (id. at p. 11, ll. 9-12).

C. Independent Claim 71

The subject matter set forth in independent claim 71 relates to a pneumatic tire 1 comprising a carcass structure 2 having at least one carcass ply 2a and at least one annular reinforcing structure 3 associated with said carcass ply 2a. (Specification at p. 8, ll. 23-31; Fig. 1). The tire 1 further comprises a tread band 6 made of an elastomeric material at a radially outer position with respect to said carcass structure 2, a belt structure 5 interposed between said carcass structure 2 and said tread band 6, and a pair of axially opposite side walls 7 on said carcass structure 2. (Id. at p. 9, ll. 1-4; Fig. 1). The tread band 6 comprises: i) at least one radially extending first sector 9 substantially of a first elastomeric material; ii) a plurality of radially extending second sectors 10 positioned at axially opposite sides of said at least one first sector 9 and substantially of a second elastomeric material; iii) at least one longitudinal groove 11 formed in said at least one first sector 9 and extending substantially for the entire circumferential development of the tread band 6 (id. at p. 9, ll. 10-19; Fig. 1); and iv) an underlayer 12 interposed between the tread band 6 and the belt structure 5 suitable for providing global rigidity to the tread, the underlayer 12 being integral with the first sector 9 and comprised substantially of the first elastomeric material (id. at p. 11, ll. 16-24). The first elastomeric material has a modulus of elasticity under compression at 23°C

greater than the modulus of elasticity under compression at 23°C of said second elastomeric material. (Id. at p. 9, ll. 24-28). The modulus of elasticity under compression at 23°C of said first elastomeric material is 20 to 80 MPa. (Id. at p. 9, l. 31, through p. 10, l. 2).

D. Independent Claim 85

The subject matter set forth in independent claim 85 relates to a process for building a pneumatic tire 1 comprising the steps of: a) building a carcass structure 2 having at least one carcass ply 2a associated with at least one annular reinforcing structure 3; b) assembling a belt structure 5 (Specification at p. 15, ll. 19-24; Figs. 1 and 6); c) arranging, at a radially outer position with respect to said belt structure 5, at least one radially extending first sector 9 of a tread band 6 (id. at p. 15, l. 25, through p. 16, l. 4), substantially of a first elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C of 20 to 80 MPa (id. at p. 16, ll. 21-25); d) arranging, at a radially outer position with respect to said belt structure 5, a plurality of radially extending second sectors 10 of the tread band 6, axially spaced apart and substantially of a second elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C lower than the value of the modulus of elasticity under compression at 23°C of said first elastomeric material (id. at p. 17, ll. 7-12); and e) arranging, at a radially outer position with respect to said belt structure 5 and a radially inner position with respect to said first and second sectors 9 and 10 (id. at p. 21, ll. 26-30), an underlayer 12 suitable for providing global rigidity to the tread band 6, the underlayer 12 being integral with the first sector 9 and comprised substantially of

the first elastomeric material (id. at p. 11, ll. 20-24); wherein said steps c) and d) are carried out in such a way that said second sectors 10 are positioned at axially opposite sides of said at least one first sector 9 (id. at p. 9, ll. 10-14).

E. Independent Claim 96

The subject matter set forth in independent claim 96 relates to a pneumatic tire 1 comprising a carcass structure 2 having at least one carcass ply 2a and at least one annular reinforcing structure 3 associated with said carcass ply 2a. (Specification at p. 8, ll. 23-31; Fig. 1). The tire 1 further comprises a tread band 6 made of an elastomeric material at a radially outer position with respect to said carcass structure 2, a belt structure 5 interposed between said carcass structure 2 and said tread band 6, and a pair of axially opposite side walls 7 on said carcass structure 2. (Id. at p. 9, ll. 1-4; Fig. 1). The tread band 6 comprises i) at least one radially extending first sector 9 substantially of a first elastomeric material; ii) a plurality of radially extending second sectors 10 positioned at axially opposite sides of said at least one first sector 9 and substantially of a second elastomeric material; iii) at least one longitudinal groove 11 formed in said at least one first sector 9 and extending substantially for the entire circumferential development of the tread band 6, the at least one longitudinal groove 11 defining a cross section (id. at p. 9, ll. 10-19; Fig. 1); and iv) an underlayer 12 interposed between the tread band 6 and the belt structure 5 suitable for providing global rigidity to the tread, the underlayer 12 being integral with the first sector 9 and comprised substantially of the first elastomeric material (id. at p. 11, ll. 16-24). The first elastomeric material has a modulus of elasticity under compression at 23°C greater than the

modulus of elasticity under compression at 23°C of said second elastomeric material. (Id. at p. 9, ll. 24-28). The modulus of elasticity under compression at 23°C of said first elastomeric material is 20 to 80 MPa. (Id. at p. 9, l. 31, through p. 10, l. 2). A ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70 (id. at p. 11, ll. 5-8), such that the cross section of the at least one longitudinal groove 11 remains substantially constant when a radially outer surface of the tread band 6 is in contact with the ground (id. at p. 11, ll. 9-12).

F. Independent Claim 108

The subject matter set forth in independent claim 108 relates to a process for building a pneumatic tire 1 comprising the steps of: a) building a carcass structure 2 having at least one carcass ply 2a associated with at least one annular reinforcing structure 3; b) assembling a belt structure 5 (Specification at p. 15, ll. 19-24; Figs. 1 and 6); c) arranging, at a radially outer position with respect to said belt structure 5, at least one radially extending first sector 9 of a tread band 6 (id. at p. 15, l. 25, through p. 16, l. 4), substantially of a first elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C of 20 to 80 MPa (id. at p. 16, ll. 21-25), the at least one radially extending first sector 9 defining a longitudinal groove 11 having a cross section (id. at p. 17, ll. 30-32). The process further comprises: d) arranging, at a radially outer position with respect to said belt structure 5, a plurality of radially extending second sectors 10 of the tread band 6, axially spaced apart and substantially of a second elastomeric material having, after vulcanization, a value of the modulus of

elasticity under compression at 23°C lower than the value of the modulus of elasticity under compression at 23°C of said first elastomeric material (id. at p. 17, ll. 7-12); and e) arranging, at a radially outer position with respect to said belt structure 5 and a radially inner position with respect to said first and second sectors 9 and 10 (id. at p. 21, ll. 26-30), an underlayer 12 suitable for providing global rigidity to the tread band 6, the underlayer 12 being integral with the first sector 9 and comprised substantially of the first elastomeric material (id. at p. 11, ll. 20-24). The steps c) and d) are carried out in such a way that said second sectors 10 are positioned at axially opposite sides of said at least one first sector 9. (Id. at p. 9, ll. 10-14). A ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70 (id. at p. 11, ll. 5-8), such that the cross section of the at least one longitudinal groove 11 remains substantially constant when a radially outer surface of the tread band 6 is in contact with the ground (id. at p. 11, ll. 9-12).

VI. Grounds of Rejection to be Reviewed on Appeal

Claims 35-41, 44-53, 69, and 70 stand rejected under 35 U.S.C. § 103(a) based on JP 53-80602 A to Fukuda ("Fukuda") in combination with U.S. Patent No. 3,773,096 to Masson ("Masson"), JP 2003-320804 A to Mine ("Mine"), "and/or" JP 2002-52906 A to Ito ("Ito"). Final Office Action at 2.

Claims 53-68 stand rejected under 35 U.S.C. § 103(a) based on Fukuda in combination with Masson, Mine, "and/or" Ito, and further in view of U.S. Patent No. 6,635,132 B2 to Caretta et al. ("Caretta"). Id. at 6.

Claims 71-84 and 96-107 stand rejected under 35 U.S.C. § 103(a) based on Fukuda "in view of (a)" Masson, Mine, and/or Ito "and (b)" EP 0 847 800 A1 to Matsuo et al. ("Matsuo") "and/or" JP 2000-118212 A to Tsuboi ("Tsuboi"). Id. at 7.

Claims 85-95 and 108-118 stand rejected under 35 U.S.C. § 103(a) based on Fukuda "in view of (a)" Masson, Mine, "and/or" Ito, "(b)" Matsuo "and/or" Tsuboi, "and (c)" Caretta. Id. at 10.

VII. Argument

Summary of Argument

The rejection of claims 35-41, 44-53, 69, and 70 under 35 U.S.C. § 103(a) based Fukuda in combination with Masson, Mine, "and/or" Ito should be reversed because independent claims 35 and 53, the only independent claims included in this claim rejection, are not prima facie obvious based on those references. Fukuda fails to disclose the subject matter alleged by the Examiner, and the differences between the subject matter recited in independent claims 35 and 53 and the combined teachings of the references are not prima facie obvious. Therefore, the § 103(a) rejection based on Fukuda in combination with Masson, Mine, "and/or" Ito should be reversed.

The rejection of claims 53-68 under 35 U.S.C. § 103(a) based on Fukuda in combination with Masson, Mine, "and/or" Ito and further in view of Caretta should be reversed because independent claim 53, the only independent claim included in this claim rejection, is not prima facie obvious based on those references. For reasons similar to those outlined above with respect to the § 103(a) rejection based on Fukuda, Masson, Mine, "and/or" Ito, Fukuda fails to disclose the subject matter alleged by the Examiner, and the differences between the subject matter recited in independent claim 53 and the combined teachings of Fukuda, Masson, Mine, Ito, and Caretta are not prima facie obvious. Therefore, the § 103(a) rejection based on Fukuda in combination with Masson, Mine, Ito, and Caretta should be reversed.

The rejection of claims 71-84 and 96-107 under 35 U.S.C. § 103(a) based on Fukuda in combination with Masson, Mine, Ito, Matsuo, and Tsuboi should be reversed because the rejected claims are not prima facie obvious based on those references.

For reasons similar to those outlined above with respect to the § 103(a) rejection based on Fukuda, Masson, Mine, "and/or" Ito, Fukuda fails to disclose the subject matter alleged by the Examiner, and the differences between the subject matter recited in claims 71, 79, and 96 and the combined teachings of Fukuda, Masson, Mine, Ito, Matsuo, and Tsuboi are not prima facie obvious. Therefore, the § 103(a) rejection based on Fukuda in combination with Masson, Mine, Ito, Matsuo, and Tsuboi should be reversed.

The rejection of claims 85-95 and 108-118 under 35 U.S.C. § 103(a) based on Fukuda in combination with Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta should be reversed because independent claims 85 and 108, the only independent claims included in this claim rejection, are not prima facie obvious based on those references. For reasons similar to those outlined above with respect to the § 103(a) rejection based on Fukuda, Masson, Mine, "and/or" Ito, Fukuda fails to disclose the subject matter alleged by the Examiner, and the differences between the subject matter recited in independent claims 85 and 108 and the combined teachings of Fukuda, Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta are not prima facie obvious. Therefore, the § 103(a) rejection based on Fukuda in combination with Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta should be reversed.

A. The Rejection of Claims 35-41, 44-53, 69, and 70 under 35 U.S.C. § 103(a) Based on Fukuda in Combination with Masson, Mine, "and/or" Ito Should Be Reversed Because Independent Claims 35 and 53 Are Not Prima Facie Obvious

Claims 35-41, 44-53, 69, and 70 were rejected under 35 U.S.C. § 103(a) based on Fukuda in combination with Masson, Mine, "and/or" Ito. Final Office Action at 2. Claims 35 and 53 are the only independent claims included in this claim rejection, and Appellant respectfully requests reversal of this claim rejection because Fukuda, Masson, Mine, and Ito fail to render independent claims 35 and 53 prima facie obvious.

Under 35 U.S.C. § 103(a), several basic factual inquires must be made in order to evaluate whether a claim is prima facie obvious. The factual inquiries are as follows:

(A) Determine the scope and contents of the prior art;

(B) Ascertain the differences between the prior art and the claims at issue;

(C) Resolve the level of ordinary skill in the pertinent art; and

(D) Evaluate evidence of secondary considerations.

Graham v. John Deere Co., 383 U.S. 1, 148 USPQ 459 (1966). Obviousness is a question of law based on these factual inquiries. Id. The question of obviousness must be resolved on the basis of these factual determinations. M.P.E.P. § 2141.*II*.

In order to avoid impermissible hindsight reasoning, the factual determinations must be made with respect to "the time the invention was made." § 2141.01(III) (emphasis added). Moreover, when "determining the differences between the prior art and the claims, the question [of obviousness] is not whether the differences themselves would have been obvious, but [rather, it is] whether the claimed invention as a whole would have been obvious." § 2141.02(I) (emphasis added).

Once the factual inquiries have been resolved, it must be determined whether a claim is prima facie obvious. § 2141(III). In order to establish a prima facie case of obviousness, "the examiner must step backward in time and into the shoes worn by the hypothetical 'person of ordinary skill in the art' when the invention was unknown and just before it was made." § 2142. Further, "the examiner must then make a determination whether the claimed invention 'as a whole' would have been obvious at that time to that person," but "[k]nowledge of applicant's disclosure must be put aside in reaching this determination" because "impermissible hindsight must be avoided and a legal conclusion must be reached on the basis of the facts gleaned from the prior art"; not on the basis of applicant's disclosure. Id. (emphasis added.)

Appellant respectfully submits that the Examiner relies on improper hindsight reasoning and Appellant's own disclosure to reject independent claims 35 and 53 because Fukuda, Masson, Mine, and Ito do not support the Examiner's obviousness allegations.

1. Independent Claim 35 Is Not Prima Facie Obvious

Independent claim 35 is directed to a pneumatic tire, including, *inter alia*,

> a tread band . . . comprising:
>
> i) at least one radially extending first sector substantially of a first elastomeric material;
>
> ii) a plurality of radially extending second sectors positioned at axially opposite sides of said at least one first sector and substantially of a second elastomeric material; [and]
>
> iii) at least one longitudinal groove formed in said at least one first sector and extending substantially for the entire

> circumferential development of the tread band, the at least one longitudinal groove defining a cross section;
>
> wherein said first elastomeric material has a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of said second elastomeric material,
>
> wherein the modulus of elasticity under compression at 23°C of said first elastomeric material is 20 to 80 MPa, and
>
> wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70 such that the cross section of the at least one longitudinal groove remains substantially constant when a radially outer surface of the tread band is in contact with the ground.

Fukuda, Masson, Mine, and Ito, regardless of whether they are viewed individually or as a whole, fail to disclose or render obvious at least this subject matter recited in independent claim 35. As a result, independent claim 35 is not prima facie obvious based on the hypothetical combination of Fukuda, Masson, Mine, and Ito.

In particular, the Fukuda, Masson, Mine, and Ito references, regardless of whether they are viewed individually or as a whole, fail to discloses or render obvious the following subject matter recited in independent claim 35:

1. at least one radially extending first sector substantially of a first elastomeric material and a plurality of radially extending second sectors substantially of a second elastomeric material, wherein the first elastomeric material has a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of the second elastomeric material;

2. wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70; or
3. first and second elastic materials having differing moduli of elasticity and hardnesses such that the cross section of at least one longitudinal groove of the tire remains substantially constant when a radially outer surface of the tread band is in contact with the ground.

For at least these reasons, independent claim 35 is not prima facie obvious based on Fukuda, Masson, Mine, and Ito.

The Examiner alleges that Fukuda "teaches a pneumatic tire construction having a tread formed of a first elastomeric material 6 and a second elastomeric material 5 (individual sectors separated by regions of first elastomeric materials), wherein said first elastomeric material is included in a groove section of the tread." Final Office Action at 2. The Examiner also alleges that "[t]he reference further teaches that the first elastomeric material provides higher wear resistance than the second elastomeric material." Id. The Examiner thereafter alleges that "[w]hile the reference fails to expressly disclose the claimed modulus, one of ordinary skill in the art at the time of the invention would have recognized such a disclosure as teaching a higher modulus for the first elastomeric material (higher modulus materials demonstrate higher wear resistance)." Id. The Examiner further alleges that "[i]t is emphasized that Fukuda generally teaches a structure in which a first elastomeric material has a greater modulus of elasticity (greater wear resistance), as compared to a second elastomeric material, without limitation." Id. at 2-3 (emphasis removed). Thereafter, the Examiner alleges

that "[o]ne of ordinary skill in the art at the time of the invention would have readily appreciated a wide variety of modulus values for each material as long as the desired wear resistance relationship (modulus relationship) is maintained between respective materials." Id. at 3. The Examiner further alleges that "[a]bsent any conclusive showing of unexpected results, one of ordinary skill in the art at the time of the invention would have found it obvious to use first and second elastomeric materials satisfying the claimed invention." Id.

Thus, the Examiner concedes that Fukuda fails to disclose a tire having a tread band including at least one radially extending first sector substantially of a first elastomeric material and a plurality of radially extending second sectors substantially of a second elastomeric material, wherein the first elastomeric material has a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of the second elastomeric material. However, the Examiner alleges that Fukuda's disclosure of tire portions having rubber with differing wear resistances results in disclosing first and second sectors of elastomeric materials having differing moduli of elasticity.

Appellant respectfully submits that the Examiner appears to be relying on a theory of inherency. Because it is not necessarily the case that rubber having a greater wear-resistance also has a greater modulus of elasticity, Fukuda fails to inherently disclose an elastomeric material having a greater modulus of elasticity. Moreover, the Examiner has not identified any prior art to support an allegation that rubber having a greater wear-resistance necessarily corresponds to an elastomeric material having a greater modulus of elasticity.

When relying on a theory of inherency, "[t]he fact that a certain result or characteristic may occur or be present in the prior art is not sufficient to establish the inherency of that result or characteristic." M.P.E.P. § 2112(IV) (citing In re Rijckaert, 9 F.3d 1531, 1534, 28 U.S.P.Q.2d 1955, 1957 (Fed. Cir. 1993); In re Oelrich, 666 F.2d 578, 581-82, 212 U.S.P.Q. 323, 326 (C.C.P.A. 1981)). In particular, "[t]o establish inherency, the extrinsic evidence 'must make clear that the missing descriptive matter is necessarily present in the thing described in the reference, and that it would be so recognized by persons of ordinary skill.'" Id. (citing In re Robertson, 169 F.3d 743, 745, 49 U.S.P.Q.2d 1949, 1950-51 (Fed. Cir. 1999) (citations omitted) (emphasis added)). Moreover, "'[t]he mere fact that a certain thing may result from a given set of circumstances is not sufficient [to establish inherency].'" Id. (emphasis added).

Appellant respectfully submits that the Examiner has failed to identify any prior art to support a theory that it is necessarily the case that rubber having a greater wear-resistance also has a greater modulus of elasticity. Indeed, it is not necessarily the case that a rubber having a greater wear-resistance also has a greater modulus of elasticity. Thus, Fukuda, which discloses a rubber having a greater wear-resistance but not an elastomeric material having a greater modulus of elasticity, does not inherently disclose an elastomeric material having a greater modulus of elasticity.

Indeed, during an interview conducted May 19, 2011, Appellant's representative discussed a paper by Alan G. Veith entitled "A Review of Important Factors Affecting Treadwear," which was presented at a meeting of the Rubber Division, American Chemical Society, in Toronto, Ontario, Canada, on May 21-24, 1991 ("the Veith paper," attached as Exhibit A in the Evidence Appendix of this Appeal Brief). The Veith paper

shows that it is not necessarily the case that a rubber having a greater wear-resistance necessarily has a greater modulus of elasticity. As set forth in the "Agenda for Examiner Interview" sent to the Examiner May 18, 2011 ("the interview agenda," attached as Exhibit B in the Evidence Appendix of this Appeal Brief), prior to the interview, the Veith paper shows that the wear resistance of rubber may be unrelated to the modulus of elasticity of the rubber. The Interview Agenda at p. 3. Indeed, as summarized in the interview agenda, the Veith paper demonstrates:

1. wear resistance appears to be entirely unrelated to the hardness of the rubber materials, as the parameter hardness is never mentioned;
2. wear resistance appears to be unrelated to the elastic modulus E' of the rubber materials, as the parameter chosen in the paper to reflect the degree of reinforcement (which has an impact on treadwear) is in fact the loss modulus E" (The Veith Paper at p. 604, last paragraph);
3. "no claim may be made that treadwear is solely related to loss modulus" (id. at p. 605, first paragraph);
4. treadwear material performance is a function of the rubber glass-transition temperature Tg and the degree of reinforcement which is dictated by the carbon black structure, surface area, and surface chemistry, in addition to the amount of carbon black in the compound; the effect of each of these is a complex function of: (i) the severity of tire use and (ii) the long term and short term environmental factors of pavement microtexture and ambient temperature (id. at p. 657, ll. 1-7);
5. increased Tg and carbon black reinforcement can improve or degrade treadwear performance depending on the external factors of pavement microtexture and ambient temperature and also on general severity of tire use (id. at p. 657, ll. 8-10);
6. treadwear performance is also influenced by the degradation characteristics of the tread compound which is influenced in turn by crosslink structure and general susceptibility to oxidation (id. at p. 657, ll. 11-13);
7. the so-called P-wear mechanism is favored by a high level of reinforcement, (i.e. a high level of the loss modulus E") abrasion resistance being attributed to low modulus (id. at p. 632, last paragraph; p. 636, comments to plots 1-3; p. 657, ll. 23-24);

8. a high degree of reinforcement (i.e. a high level of the loss modulus E") is not necessarily good, since modulus is increased along with an increase in strength and this increase may outbalance the increased reinforcement strength for a net increase in abrasion (id. at p. 633, first paragraph); and

9. P-wear is favored by hard compounds (high black level that is with high level of the loss modulus E") (id. at p. 635, first paragraph).

Thus, contrary the Examiner's allegation that rubber having a higher wear-resistance, as disclosed in Fukuda, would have a higher modulus of elasticity, the Veith paper shows wear-resistance may be unrelated to modulus of elasticity. Thus, it is not necessarily the case that rubber having a higher wear-resistance will also have a higher modulus of elasticity. As a result, Fukuda, in addition to not expressly disclosing at least one first sector substantially of a first elastomeric material and a plurality of second sectors of substantially a second elastomeric material, also fails to inherently disclose this subject matter recited in independent claim 35.

Masson, Mine, and Ito do not overcome this deficiency of the § 103(a) rejection of independent claim 35. For at least this reason, independent claim 35 is not prima facie obvious based on Fukuda, Masson, Mine, and Ito, and Appellant respectfully requests reversal of this claim rejection.

In addition, Fukuda also fails to disclose first and second elastomeric materials, wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70, as recited in independent claim 35. The rejection of claim 35 does not address this subject matter recited in independent claim 35. See Final Office Action at 2-3. Appellant respectfully submits that none of the Fukuda, Masson, Mine, and Ito references discloses or renders obvious this subject matter.

In the "*Response to Arguments*" section of the final Office Action, the Examiner alleges that "Fukuda expressly depicts multiple tire constructions having grooves in a first tread sector, wherein said sector has a greater wear resistance, and thus a greater hardness and modulus, than an adjacent second tread sector." Final Office Action at 12. Thus, the Examiner is equating a rubber having a greater wear-resistance with an elastomeric material having a greater hardness.

Fukuda does not expressly disclose the relative hardness of the tire portions having differing wear-resistances, and thus, the Examiner appears to be relying on a theory that Fukuda inherently discloses first sectors of a first elastomeric material having a greater hardness than a second elastomeric material of second sectors. However, the Examiner has not identified any support in the prior art that greater wear-resistance necessarily results in greater hardness. For at least this additional reason, Fukuda fails to inherently disclose the hardness characteristic recited in independent claim 35.

Indeed, the wear-resistance of an elastomeric material may be unrelated to its hardness. The Veith paper discussed during the interview shows that it is not necessarily the case that a rubber having a greater wear-resistance also has a greater hardness. As set forth in the interview agenda, the Veith paper shows that the wear-resistance of rubber may be unrelated to its hardness. The Interview Agenda at p. 3. As noted in the interview agenda, based on the Veith paper wear resistance appears to be entirely unrelated to the hardness of rubber, as the parameter of hardness is never mentioned in the Veith paper, which relates to wear-resistance. Thus, contrary the Examiner's allegation that rubber having a higher wear-resistance would have a higher

hardness, the Veith paper shows wear-resistance may be unrelated to hardness. As a result, it is not necessarily the case that rubber having a higher wear-resistance will also have a higher hardness. Therefore, Fukuda fails to disclose, either expressly or inherently, or render obvious first and second elastomeric materials, wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70, as recited in independent claim 35.

Masson, Mine, and Ito do not overcome this deficiency of the § 103(a) rejection of independent claim 35. For at least this additional reason, independent claim 35 is not prima facie obvious based on Fukuda, Masson, Mine, and Ito, and Appellant respectfully requests reversal of this claim rejection.

In addition to the above-noted reasons, independent claim 35 is not prima facie obvious based on Fukuda, Masson, Mine, and Ito because Fukuda also fails to disclose first and second elastomeric materials having differing hardnesses, such that the cross-section of at least one longitudinal groove of the tire remains substantially constant when a radially outer surface of the tread band is in contact with the ground, as recited in independent claim 35. The rejection of claim 35 does not address this subject matter recited in independent claim 35. See Final Office Action at 2-3. Appellant respectfully submits that the Fukuda, Masson, Mine, and Ito references, regardless of whether they are viewed individually or as a whole, fail to discloses or render obvious this subject matter.

In the "*Response to Arguments*" section of the final Office Action, the Examiner alleges that "Fukuda expressly depicts multiple tire constructions having grooves in a

first tread sector, wherein said sector has a greater wear resistance, and thus a greater hardness and modulus, than an adjacent second tread sector." Id. Based on this allegation, the Examiner further alleges that "one would similarly expect the cross section of the grooves of Fukuda to remain substantially constant when a radially outer surface of the tread band is in contact with the ground." Id.

Thus, the Examiner relies on the allegations that Fukuda inherently discloses a tire having first and second sectors of elastomeric materials having differing moduli of elasticity and hardness to support the allegation that Fukuda teaches a tire having at least one longitudinally extending groove that remains substantially constant when a radially outer surface of the tread band is in contact with the ground. For at least the reasons noted above, Fukuda fails to disclose or render obvious first and second elastomeric materials having differing moduli of elasticity or hardness. For at least this reason, it is not necessarily the case that the longitudinally extending groove disclosed in Fukuda has a cross-section that remains substantially constant when a radially outer surface of the tread band is in contact with the ground.

Masson, Mine, and Ito do not overcome this deficiency of the § 103(a) rejection of independent claim 35. For at least this additional reason, independent claim 35 is not prima facie obvious based on Fukuda, Masson, Mine, and Ito, and Appellant respectfully requests reversal of this claim rejection.

To summarize, Fukuda fails to disclose, either expressly or inherently, or render obvious:

1. at least one radially extending first sector substantially of a first elastomeric material and a plurality of radially extending second sectors

substantially of a second elastomeric material, wherein the first elastomeric material has a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of the second elastomeric material;

2. wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70; or
3. first and second elastic materials having differing moduli of elasticity and hardnesses such that the cross section of at least one longitudinal groove of the tire remains substantially constant when a radially outer surface of the tread band is in contact with the ground.

Masson, Mine, and Ito do not overcome these deficiencies of Fukuda.

For at least these reasons, the prior art does not support the claim rejection. Thus, the Examiner must be relying on improper hindsight reasoning and Appellant's disclosure in rejecting independent claim 35. Therefore, independent claim 35 is not prima facie obvious based on Fukuda, Masson, Mine, and Ito. Claims 36-41 and 44-52, also rejected under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, and Ito, depend from independent claim 35, and thus, they are patentably distinguishable from those references for at least the same reasons as independent claim 35. Therefore, Appellant respectfully requests reversal of the rejection of claims 35-41 and 44-52 under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, and Ito.

2. Independent Claim 53 Is Not Prima Facie Obvious

Independent claim 53 is directed to a process for building a pneumatic tire, the process including, *inter alia*,

> c) arranging, at a radially outer position with respect to [a] belt structure, at least one radially extending first sector of a tread band, substantially of a first elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C of 20 to 80 MPa, the at least one radially extending first sector defining a longitudinally extending groove having a cross section; and
>
> d) arranging, at a radially outer position with respect to said belt structure, a plurality of radially extending second sectors of the tread band, axially spaced apart and substantially of a second elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C lower than the value of the modulus of elasticity under compression at 23°C of said first elastomeric material;
>
> . . .
>
> wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70 such that the cross section of the at least one longitudinal groove remains substantially constant when a radially outer surface of the tread band is in contact with the ground.

Fukuda, Masson, Mine, and Ito, regardless of whether they are viewed individually or as a whole, fail to disclose or render obvious at least this subject matter recited in independent claim 53. As a result, independent claim 53 is not prima facie obvious based on the hypothetical combination of Fukuda, Masson, Mine, and Ito.

For reasons similar to those outlined above with respect to the rejection of independent claim 35, the Fukuda, Masson, Mine, and Ito references, regardless of

whether they are viewed individually or as a whole, fail to discloses or render obvious the following subject matter recited in independent claim 53:

1. arranging at least one radially extending first sector substantially of a first elastomeric material, and arranging a plurality of radially extending second sectors substantially of a second elastomeric material having a value of modulus of elasticity under compression at 23°C lower than a value of the modulus of elasticity under compression at 23°C of the first elastomeric material;
2. a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70; or
3. first and second elastic materials having differing moduli of elasticity and hardnesses such that the cross-section of at least one longitudinal groove of the tire remains substantially constant when a radially outer surface of the tread band is in contact with the ground.

Therefore, independent claim 53 is not prima facie obvious based on Fukuda, Masson, Mine, and Ito. Claims 69 and 70, also rejected under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, and Ito, depend from independent claim 53, and thus, they are patentably distinguishable from those references for at least the same reasons as independent claim 53. Therefore, Appellant respectfully requests reversal of the rejection of claims 53, 69 and 70 under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, and Ito.

B. The Rejection of Claims 53-68 Under 35 U.S.C. § 103(a) Based on Fukuda in Combination with Masson, Mine, "and/or" Ito and Further in View of Caretta Should Be Reversed Because Independent claim 53, the Only Independent Claim Included in This Claim Rejection, Is Not Prima Facie Obvious

Claim 53 is the only independent claim included in this claim rejection. For at least the reasons outlined above with respect to the rejection of independent claim 53 under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, and Ito, independent claim 53 is patentably distinguishable from those references. Caretta, cited for its purported disclosure of known manufacturing methods (Final Office Action at 6), fails to overcome the deficiencies noted previously herein with respect to the § 103(a) rejection based on Fukuda, Masson, Mine, and Ito. For at least this reason, independent claim 53 is patentably distinguishable from Fukuda, Masson, Mine, Ito, and Caretta. Claims 54-68, also included in this claim rejection, depend from independent claim 53, and thus, they should be patentably distinguishable from Fukuda, Masson, Mine, Ito, and Caretta for at least the same reasons as independent claim 53. Therefore, Appellant respectfully requests reversal of the rejection of claims 53-68 under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, Ito, and Caretta.

C. The Rejection of Claims 71-84 and 96-107 Under 35 U.S.C. § 103(a) Based on Fukuda in Combination with Masson, Mine, Ito, Matsuo, and Tsuboi Should Be Reversed Because the Rejected Claims Are Not Prima Facie Obvious

Claims 71-84 and 96-107 were rejected under 35 U.S.C. § 103(a) based on Fukuda in combination with Masson, Mine, Ito, Matsuo, and Tsuboi. Final Office Action at 7. Claims 71 and 96 are the only independent claims included in this claim rejection, and Appellant respectfully requests reversal of this claim rejection because Fukuda,

Masson, Mine, Ito, Matsuo, and Tsuboi fail to render independent claims 71 and 96 prima facie obvious. In addition, Fukuda, Masson, Mine, Ito, Matsuo, and Tsuboi fail to render at least dependent claim 79 prima facie obvious for additional reasons.

1. Independent Claim 71 Is Not Prima Facie Obvious

Independent claim 71 is directed to a pneumatic tire, including, *inter alia*,

> a tread band . . . comprising:
>
> i) at least one radially extending first sector substantially of a first elastomeric material;
>
> ii) a plurality of radially extending second sectors positioned at axially opposite sides of said at least one first sector and substantially of a second elastomeric material; [and]
>
> iii) at least one longitudinal groove formed in said at least one first sector and extending substantially for the entire circumferential development of the tread band, the at least one longitudinal groove defining a cross section;
>
> . . .
>
> wherein said first elastomeric material has a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of said second elastomeric material, and
>
> wherein the modulus of elasticity under compression at 23°C of said first elastomeric material is 20 to 80 MPa.

Fukuda, Masson, Mine, Ito, Matsuo, and Tsuboi, regardless of whether they are viewed individually or as a whole, fail to disclose or render obvious at least this subject matter recited in independent claim 71. As a result, independent claim 71 is not prima facie obvious based on the hypothetical combination of Fukuda, Masson, Mine, Ito, Matsuo, and Tsuboi.

In particular, the Fukuda, Masson, Mine, Ito, Matsuo, and Tsuboi references, regardless of whether they are viewed individually or as a whole, fail to discloses or render obvious a first elastomeric material having a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of the second elastomeric material. For at least the reasons outlined above with respect to independent claim 35, Fukuda, Masson, Mine, and Ito fail to disclose or render obvious at least this subject matter recited in independent claim 71. Matsuo and Tsuboi, cited for their purported disclosures of connected or joined ground contacting sectors (Final Office Action at 7), fail to overcome the deficiencies of Fukuda, Masson, Mine, and Ito. For at least these reasons, independent claim 71 is not prima facie obvious based on Fukuda, Masson, Mine, Ito, Matsuo, and Tsuboi. Claims 72-84, also included in this claim rejection, depend from independent claim 71, and thus, they are patentably distinguishable from those references for at least the same reasons as independent claim 71. Therefore, Appellant respectfully requests reversal of the rejection of claims 71-84 under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, Ito, Matsuo, and Tsuboi.

2. Dependent Claim 79 Is Not Prima Facie Obvious

Claim 79 depends from independent claim 71, and thus, claim 79 is patentably distinguishable from Fukuda, Masson, Mine, Ito, Matsuo, and Tsuboi for at least the same reasons as independent claim 71. In addition, claim 79 recites additional subject matter that *further* distinguishes it from those references.

In particular, claim 79 recites, "wherein the ratio between the IRHD hardness at 23°C of the first elastomeric material, measured according to standard ISO 48, and the IRHD hardness at 23°C of the second elastomeric material, measured according to standard ISO 48, is about 1.15 to about 2.70." For at least the reason outlined previously herein with respect to the rejection of independent claim 35, Fukuda, Masson, Mine, and Ito, regardless of whether they are viewed individually or as a whole, fail to disclose or render obvious at least this subject matter recited in claim 79. Moreover, Matsuo and Tsuboi, cited for their purported disclosures of connected or joined ground contacting sectors (Final Office Action at 7), fail to overcome the deficiencies of Fukuda, Masson, Mine, and Ito. For at least this additional reason, claim 79 is not prima facie obvious based on Fukuda, Masson, Mine, Ito, Matsuo, and Tsuboi. Therefore, Appellant respectfully requests reversal of the rejection of claim 79 under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, Ito, Matsuo, and Tsuboi.

3. Independent Claim 96 Is Not Prima Facie Obvious

Independent claim 96 is directed to a pneumatic tire, including, *inter alia*,

> a tread band . . . comprising:
>
> i) at least one radially extending first sector substantially of a first elastomeric material;
>
> ii) a plurality of radially extending second sectors positioned at axially opposite sides of said at least one first sector and substantially of a second elastomeric material; [and]
>
> iii) at least one longitudinal groove formed in said at least one first sector and extending substantially for the entire circumferential development of the tread band, the at least one longitudinal groove defining a cross section;

wherein said first elastomeric material has a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of said second elastomeric material,

wherein the modulus of elasticity under compression at 23°C of said first elastomeric material is 20 to 80 MPa, and

wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70 such that the cross section of the at least one longitudinal groove remains substantially constant when a radially outer surface of the tread band is in contact with the ground.

For at least the reasons outlined above with respect to the rejection of independent claim 35 under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, and Ito, independent claim 96 is patentably distinguishable from those references. Matsuo and Tsuboi, cited for their purported disclosures of connected or joined ground contacting sectors (Final Office Action at 7), fail to overcome the deficiencies of Fukuda, Masson, Mine, and Ito. For at least this reason, independent claim 96 is patentably distinguishable from Fukuda, Masson, Mine, Ito, Matsuo and Tsuboi. Claims 97-107, also included in this claim rejection, depend from independent claim 96, and thus, they are patentably distinguishable from Fukuda, Masson, Mine, Ito, Matsuo and Tsuboi for at least the same reasons as independent claim 96. Therefore, Appellant respectfully requests reversal of the rejection of claims 96-107 under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, Ito, Matsuo and Tsuboi.

D. The Rejection of Claims 85-95 and 108-118 Under 35 U.S.C. § 103(a) Based on Fukuda in Combination with Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta Should Be Reversed Because Independent Claims 85 and 108, the Only Independent Claims Included in this Claim Rejection, Are Not Prima Facie Obvious

Claims 85-95 and 108-118 were rejected under 35 U.S.C. § 103(a) based on Fukuda in combination with Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta. Final Office Action at 10. Claims 85 and 108 are the only independent claims included in this claim rejection, and Appellant respectfully requests reversal of this claim rejection because Fukuda, Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta fail to render independent claims 85 and 108 prima facie obvious.

1. Independent Claim 85 Is Not Prima Facie Obvious

Independent claim 85 is directed to a process for building a pneumatic tire, including, *inter alia*,

> c) arranging, at a radially outer position with respect to [a] belt structure, at least one radially extending first sector of a tread band, substantially of a first elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C of 20 to 80 MPa; [and]
>
> d) arranging, at a radially outer position with respect to said belt structure, a plurality of radially extending second sectors of the tread band, axially spaced apart and substantially of a second elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C lower than the value of the modulus of elasticity under compression at 23°C of said first elastomeric material . . . .

Fukuda, Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta, regardless of whether they are viewed individually or as a whole, fail to disclose or render obvious at least this subject matter recited in independent claim 85. As a result, independent claim 85 is not

prima facie obvious based on the hypothetical combination of Fukuda, Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta.

In particular, the Fukuda, Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta references, regardless of whether they are viewed individually or as a whole, fail to disclose or render obvious arranging at least one radially extending first sector substantially of a first elastomeric material, and arranging a plurality of radially extending second sectors substantially of a second elastomeric material having a value of modulus of elasticity under compression at 23°C lower than a value of the modulus of elasticity under compression at 23°C of the first elastomeric material. For at least the reasons outlined above with respect to the rejection of independent claim 53, Fukuda, Masson, Mine, and Ito fail to disclose or render obvious at least this subject matter recited in independent claim 85. Matsuo and Tsuboi, cited for their purported disclosures of connected or joined ground contacting sectors (Final Office Action at 7), and Caretta, cited for its purported disclosure of known manufacturing methods (Final Office Action at 6), fail to overcome the deficiencies of Fukuda, Masson, Mine, and Ito. For at least these reasons, independent claim 85 is not prima facie obvious based on Fukuda, Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta. Claims 86-95, also included in this claim rejection, depend from independent claim 85, and thus, they are patentably distinguishable from those references for at least the same reasons as independent claim 85. Therefore, Appellant respectfully requests reversal of the rejection of claims 85-95 under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta.

2. Independent Claim 108 Is Not Prima Facie Obvious

Independent claim 108 is directed to a process for building a pneumatic tire, the process including, *inter alia*,

> c) arranging, at a radially outer position with respect to said belt structure, at least one radially extending first sector of a tread band, substantially of a first elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C of 20 to 80 MPa, the at least one radially extending first sector defining a longitudinal groove having a cross section; [and]
>
> d) arranging, at a radially outer position with respect to said belt structure, a plurality of radially extending second sectors of the tread band, axially spaced apart and substantially of a second elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C lower than the value of the modulus of elasticity under compression at 23°C of said first elastomeric material;
>
> . . .
>
> wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70 such that the cross section of the at least one longitudinal groove remains substantially constant when a radially outer surface of the tread band is in contact with the ground.

For at least the reasons outlined above with respect to the rejection of independent claim 53 under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, and Ito, independent claim 108 is patentably distinguishable from those references. Matsuo and Tsuboi, cited for their purported disclosures of connected or joined ground contacting sectors (Final Office Action at 7), and Caretta, cited for its purported disclosure of known manufacturing methods (Final Office Action at 6), fail to overcome the deficiencies of Fukuda, Masson, Mine, and Ito. For at least this reason, independent

claim 108 is patentably distinguishable from Fukuda, Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta. Claims 109-118, also included in this claim rejection, depend from independent claim 108, and thus, they should be patentably distinguishable from Fukuda, Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta for at least the same reasons as independent claim 108. Therefore, Appellant respectfully requests reversal of the rejection of claims 108-118 under 35 U.S.C. § 103(a) based on Fukuda, Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta.

E. Conclusion

For the at least the above-outlined reasons, pending claims 35-41 and 44-118 are patentably distinguishable from Fukuda, Masson, Mine, Ito, Matsuo, Tsuboi, and Caretta, regardless of whether those references are viewed individually or as a whole. The Board is therefore respectfully requested to reverse the claim rejections under 35 U.S.C. § 103(a), so that pending claims 35-41 and 44-118 may be allowed.

To the extent any extension of time under 37 C.F.R. § 1.136 is required to obtain entry of this Appeal Brief, such extension is hereby respectfully requested. If there are any fees due which are not included herewith, please charge such fees to our Deposit Account 06-0916.

Respectfully submitted,
FINNEGAN, HENDERSON, FARABOW,
GARRETT & DUNNER, L.L.P.

Dated: July 6, 2011

By:____________________
Christopher T. Kent
Reg. No. 48,216

VIII. Claims Appendix

35. A pneumatic tire comprising a carcass structure having at least one carcass ply and at least one annular reinforcing structure associated with said carcass ply, a tread band made of an elastomeric material at a radially outer position with respect to said carcass structure, a belt structure interposed between said carcass structure and said tread band and a pair of axially opposite side walls on said carcass structure, the tread band comprising:

i) at least one radially extending first sector substantially of a first elastomeric material;

ii) a plurality of radially extending second sectors positioned at axially opposite sides of said at least one first sector and substantially of a second elastomeric material;

iii) at least one longitudinal groove formed in said at least one first sector and extending substantially for the entire circumferential development of the tread band, the at least one longitudinal groove defining a cross section;

wherein said first elastomeric material has a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of said second elastomeric material,

wherein the modulus of elasticity under compression at 23°C of said first elastomeric material is 20 to 80 MPa, and

wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70 such that the cross section of the at least one longitudinal groove remains

substantially constant when a radially outer surface of the tread band is in contact with the ground.

36. The pneumatic tire according to claim 35, wherein the modulus of elasticity under compression at 23°C of said second elastomeric material is about 4 to about 15 MPa.

37. The pneumatic tire according to claim 35, wherein the ratio between the modulus of elasticity under compression at 23°C of the first elastomeric material and the modulus of elasticity under compression at 23°C of the second elastomeric material of the tread band is not lower than about 1.30.

38. The pneumatic tire according to claim 37, wherein the ratio between the modulus of elasticity under compression at 23°C of the first elastomeric material and the modulus of elasticity under compression at 23°C of the second elastomeric material is about 1.5 to about 20.

39. The pneumatic tire according to claim 38, wherein the ratio between the modulus of elasticity under compression at 23°C of the first elastomeric material and the modulus of elasticity under compression at 23°C of the second elastomeric material is about 2.3 to about 7.

40. The pneumatic tire according to claim 35, wherein the IRHD hardness at 23°C of the first elastomeric material, measured according to standard ISO 48, is about 75 to about 95.

41. The pneumatic tire according to claim 35, wherein the IRHD hardness at 23°C of the second elastomeric material, measured according to standard ISO 48, is about 35 to about 80.

44. The pneumatic tire according to claim 35, wherein the tread band is provided with a plurality of longitudinal grooves and wherein said grooves are formed in respective first sectors, radially extending and axially spaced apart, substantially of said first elastomeric material.

45. The pneumatic tire according to claim 35, wherein said at least one first sector is radially extending substantially for the entire thickness of the tread band.

46. The pneumatic tire according to claim 35, wherein an additional layer of elastomeric material is interposed between said tread band and said belt structure.

47. The pneumatic tire according to claim 46, wherein said layer is substantially of said first elastomeric material.

48. The pneumatic tire according to claim 46, wherein said additional layer is substantially of said second elastomeric material.

49. The pneumatic tire according to claim 46, wherein said layer has a thickness of 1 to 5 mm.

50. The pneumatic tire according to claim 35, wherein the width of said at least one first sector is at least equal to the width of said at least one longitudinal groove.

51. The pneumatic tire according to claim 50, wherein the difference between the width of said at least one first sector and the width of said at least one longitudinal groove is 4 to 10 mm.

52. The pneumatic tire according to claim 35, wherein said at least one longitudinal groove is positioned astride the median plane of said at least one first sector.

53. A process for building a pneumatic tire comprising the steps of:

a) building a carcass structure having at least one carcass ply associated with at least one annular reinforcing structure;

b) assembling a belt structure;

c) arranging, at a radially outer position with respect to said belt structure, at least one radially extending first sector of a tread band, substantially of a first elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C of 20 to 80 MPa, the at least one radially extending first sector defining a longitudinally extending groove having a cross section; and

d) arranging, at a radially outer position with respect to said belt structure, a plurality of radially extending second sectors of the tread band, axially spaced apart and substantially of a second elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C lower than the value of the modulus of elasticity under compression at 23°C of said first elastomeric material;

wherein said steps c) and d) are carried out in such a way that said second sectors are positioned at axially opposite sides of said at least one first sector, and

wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70 such that the cross section of the at least one longitudinal groove remains substantially constant when a radially outer surface of the tread band is in contact with the ground.

54. The process according to claim 53, wherein said belt structure is shaped on a substantially cylindrical auxiliary drum and wherein said steps c) and d) comprise the steps of:

e) positioning said auxiliary drum at a first delivery member of the first elastomeric material;

f) delivering by means of said first delivery member at least one elongated element made of said first elastomeric material at a radially outer position with respect to said belt structure while carrying out a relative displacement between the first delivery member and the auxiliary drum, so as to form said at least one first sector of the tread band;

g) positioning the auxiliary drum at a second delivery member of the second elastomeric material; and

h) delivering by means of said second delivery member at least one elongated element made of said second elastomeric material at a radially outer position

with respect to said belt structure while carrying out a relative displacement between the second delivery member and the auxiliary drum so as to form said second sectors of the tread band axially spaced apart and positioned at opposite sides of said at least one first sector.

55. The process according to claim 54, wherein said steps f) and h) of delivering the elongated elements of said first and second elastomeric materials are carried out by rotating said auxiliary drum about its rotation axis.

56. The process according to claim 54, wherein the relative displacement between the delivery member and the auxiliary drum is carried out by imparting to the auxiliary drum a first translational movement along a direction substantially parallel to its rotation axis and/or a second translational movement along a direction substantially perpendicular to said axis.

57. The process according to claim 54, wherein said steps f) and h) of delivering the elongated elements of said first and second elastomeric materials are carried out by forming a plurality of coils axially arranged side-by-side and/or radially superposed to define said at least one first and said second sectors of the tread band.

58. The process according to claim 53, wherein said belt structure is assembled on a substantially toroidal support and wherein said steps c) and d) comprise the steps of:

e') positioning said substantially toroidal support at a first delivery member of the first elastomeric material;

f') delivering by means of said first delivery member at least one elongated element made of said first elastomeric material at a radially outer position with respect to said belt structure while carrying out a relative displacement between the first delivery member and the substantially toroidal support, so as to form said at least one first sector of the tread band;

g') positioning the substantially toroidal support at a second delivery member of the second elastomeric material; and

h') delivering by means of said second delivery member at least one elongated element made of said second elastomeric material at a radially outer position with respect to said belt structure while carrying out a relative displacement between the second delivery member and the substantially toroidal support, so as to form said second sectors of tread band axially spaced apart and positioned at axially opposite sides of said at least one first sector.

59. The process according to claim 58, wherein said steps f') and h') of delivering the elongated elements of said first and second elastomeric materials are carried out by rotating said substantially toroidal support about its rotation axis.

60. The process according to claim 58, wherein the relative displacement between the delivery member and the substantially toroidal support is carried out by imparting to the substantially toroidal support a first translational movement along a direction substantially parallel to its rotation axis and/or a second translational movement along a direction substantially perpendicular to said axis.

61. The process according to claim 58, wherein said steps f') and h') of delivering the elongated elements of said first and second elastomeric materials are carried out by forming a plurality of coils axially arranged side-by-side and/or radially superposed to define said at least one first and said second sectors of the tread band.

62. The process according to claim 58, wherein said substantially toroidal support is substantially rigid.

63. The process according to claim 53, further comprising the step of delivering, at a radially outer position with respect to said belt structure, at least one additional layer of elastomeric material before carrying out said step c) of delivering said at least one first sector.

64. The process according to claim 53, further comprising the step of delivering, at a radially outer position with respect to said belt structure, at least one additional layer of elastomeric material simultaneously with said step c) of delivering said at least one first sector.

65. The process according to claim 53, further comprising the step of delivering, at a radially outer position with respect to said belt structure, at least one additional layer of elastomeric material before carrying out said step d) of delivering said plurality of second sectors.

66. The process according to claim 53, further comprising the step of delivering, at a radially outer position with respect to said belt structure, at least one

additional layer of elastomeric material simultaneously with said step d) of delivering said plurality of second sectors.

67. The process according to claim 63, wherein said layer is substantially of said first elastomeric material.

68. The process according to claim 63, wherein said layer is substantially of said second elastomeric material.

69. The pneumatic tire according to claim 35, wherein the modulus of elasticity under compression at 23°C of said first elastomeric material is about 30 to about 80 MPa.

70. The process according to claim 53, wherein the modulus of elasticity under compression at 23°C of said first elastomeric material is about 30 to about 80 MPa.

71. A pneumatic tire comprising a carcass structure having at least one carcass ply and at least one annular reinforcing structure associated with said carcass ply, a tread band made of an elastomeric material at a radially outer position with respect to said carcass structure, a belt structure interposed between said carcass structure and said tread band and a pair of axially opposite side walls on said carcass structure, the tread band comprising:

i) at least one radially extending first sector substantially of a first elastomeric material;

ii) a plurality of radially extending second sectors positioned at axially opposite sides of said at least one first sector and substantially of a second elastomeric material;

iii) at least one longitudinal groove formed in said at least one first sector and extending substantially for the entire circumferential development of the tread band; and

iv) an underlayer interposed between the tread band and the belt structure suitable for providing global rigidity to the tread, the underlayer being integral with the first sector and comprised substantially of the first elastomeric material;

wherein said first elastomeric material has a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of said second elastomeric material, and

wherein the modulus of elasticity under compression at 23°C of said first elastomeric material is 20 to 80 MPa.

72. The pneumatic tire according to claim 71, wherein the modulus of elasticity under compression at 23°C of said second elastomeric material is about 4 to about 15 MPa.

73. The pneumatic tire according to claim 71, wherein the ratio between the modulus of elasticity under compression at 23°C of the first elastomeric material and the modulus of elasticity under compression at 23°C of the second elastomeric material of the tread band is not lower than about 1.30.

74. The pneumatic tire according to claim 73, wherein the ratio between the modulus of elasticity under compression at 23°C of the first elastomeric material and the modulus of elasticity under compression at 23°C of the second elastomeric material is about 1.5 to about 20.

75. The pneumatic tire according to claim 74, wherein the ratio between the modulus of elasticity under compression at 23°C of the first elastomeric material and the modulus of elasticity under compression at 23°C of the second elastomeric material is about 2.3 to about 7.

76. The pneumatic tire according to claim 71, wherein the IRHD hardness at 23°C of the first elastomeric material, measured according to standard ISO 48, is about 75 to about 95.

77. The pneumatic tire according to claim 71, wherein the IRHD hardness at 23°C of the second elastomeric material, measured according to standard ISO 48, is about 35 to about 80.

78. The pneumatic tire according to claim 71, wherein the ratio between the IRHD hardness at 23°C of the first elastomeric material, measured according to standard ISO 48, and the IRHD hardness at 23°C of the second elastomeric material, measured according to standard ISO 48, is not lower than about 1.10.

79. The pneumatic tire according to claim 78, wherein the ratio between the IRHD hardness at 23°C of the first elastomeric material, measured according to

standard ISO 48, and the IRHD hardness at 23°C of the second elastomeric material, measured according to standard ISO 48, is about 1.15 to about 2.70.

80. The pneumatic tire according to claim 71, wherein the tread band is provided with a plurality of longitudinal grooves and wherein said grooves are formed in respective first sectors, radially extending and axially spaced apart, substantially of said first elastomeric material.

81. The pneumatic tire according to claim 71, wherein said layer has a thickness of 1 to 5 mm.

82. The pneumatic tire according to claim 71, wherein the width of said at least one first sector is at least equal to the width of said at least one longitudinal groove.

83. The pneumatic tire according to claim 82, wherein the difference between the width of said at least one first sector and the width of said at least one longitudinal groove is 4 to 10 mm.

84. The pneumatic tire according to claim 71, wherein said at least one longitudinal groove is positioned astride the median plane of said at least one first sector.

85. A process for building a pneumatic tire comprising the steps of:

a) building a carcass structure having at least one carcass ply associated with at least one annular reinforcing structure;

b) assembling a belt structure;

c) arranging, at a radially outer position with respect to said belt structure, at least one radially extending first sector of a tread band, substantially of a first elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C of 20 to 80 MPa;

d) arranging, at a radially outer position with respect to said belt structure, a plurality of radially extending second sectors of the tread band, axially spaced apart and substantially of a second elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C lower than the value of the modulus of elasticity under compression at 23°C of said first elastomeric material; and

e) arranging, at a radially outer position with respect to said belt structure and a radially inner position with respect to said first and second sectors, an underlayer suitable for providing global rigidity to the tread band, the underlayer being integral with the first sector and comprised substantially of the first elastomeric material;

wherein said steps c) and d) are carried out in such a way that said second sectors are positioned at axially opposite sides of said at least one first sector.

86. The process according to claim 85, wherein said belt structure is shaped on a substantially cylindrical auxiliary drum and wherein said steps c) and d) comprise the steps of:

f) positioning said auxiliary drum at a first delivery member of the first elastomeric material;

g) delivering by means of said first delivery member at least one elongated element made of said first elastomeric material at a radially outer position with respect to said belt structure while carrying out a relative displacement between the first delivery member and the auxiliary drum, so as to form said at least one first sector of the tread band;

h) positioning the auxiliary drum at a second delivery member of the second elastomeric material; and

i) delivering by means of said second delivery member at least one elongated element made of said second elastomeric material at a radially outer position with respect to said belt structure while carrying out a relative displacement between the second delivery member and the auxiliary drum so as to form said second sectors of the tread band axially spaced apart and positioned at opposite sides of said at least one first sector.

87. The process according to claim 86, wherein said steps g) and i) of delivering the elongated elements of said first and second elastomeric materials are carried out by rotating said auxiliary drum about its rotation axis.

88. The process according to claim 86, wherein the relative displacement between the delivery member and the auxiliary drum is carried out by imparting to the auxiliary drum a first translational movement along a direction substantially parallel to its rotation axis and/or a second translational movement along a direction substantially perpendicular to said axis.

89. The process according to claim 86, wherein said steps g) and i) of delivering the elongated elements of said first and second elastomeric materials are carried out by forming a plurality of coils axially arranged side-by-side and/or radially superposed to define said at least one first and said second sectors of the tread band.

90. The process according to claim 85, wherein said belt structure is assembled on a substantially toroidal support and wherein said steps c) and d) comprise the steps of:

e') positioning said substantially toroidal support at a first delivery member of the first elastomeric material;

f') delivering by means of said first delivery member at least one elongated element made of said first elastomeric material at a radially outer position with respect to said belt structure while carrying out a relative displacement between the first delivery member and the substantially toroidal support, so as to form said at least one first sector of the tread band;

g') positioning the substantially toroidal support at a second delivery member of the second elastomeric material; and

h') delivering by means of said second delivery member at least one elongated element made of said second elastomeric material at a radially outer position with respect to said belt structure while carrying out a relative displacement between the second delivery member and the substantially toroidal support, so as to form said second sectors of tread band axially spaced apart and positioned at axially opposite sides of said at least one first sector.

91. The process according to claim 90, wherein said steps f') and h') of delivering the elongated elements of said first and second elastomeric materials are carried out by rotating said substantially toroidal support about its rotation axis.

92. The process according to claim 90, wherein the relative displacement between the delivery member and the substantially toroidal support is carried out by imparting to the substantially toroidal support a first translational movement along a direction substantially parallel to its rotation axis and/or a second translational movement along a direction substantially perpendicular to said axis.

93. The process according to claim 90, wherein said steps f') and h') of delivering the elongated elements of said first and second elastomeric materials are carried out by forming a plurality of coils axially arranged side-by-side and/or radially superposed to define said at least one first and said second sectors of the tread band.

94. The process according to claim 90, wherein said substantially toroidal support is substantially rigid.

95. The process according to claim 85, wherein the underlayer has a thickness of 1 to 5 mm.

96. A pneumatic tire comprising a carcass structure having at least one carcass ply and at least one annular reinforcing structure associated with said carcass ply, a tread band made of an elastomeric material at a radially outer position with respect to said carcass structure, a belt structure interposed between said carcass

structure and said tread band and a pair of axially opposite side walls on said carcass structure, the tread band comprising:

i) at least one radially extending first sector substantially of a first elastomeric material;

ii) a plurality of radially extending second sectors positioned at axially opposite sides of said at least one first sector and substantially of a second elastomeric material;

iii) at least one longitudinal groove formed in said at least one first sector and extending substantially for the entire circumferential development of the tread band, the at least one longitudinal groove defining a cross section; and

iv) an underlayer interposed between the tread band and the belt structure suitable for providing global rigidity to the tread, the underlayer being integral with the first sector and comprised substantially of the first elastomeric material;

wherein said first elastomeric material has a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of said second elastomeric material,

wherein the modulus of elasticity under compression at 23°C of said first elastomeric material is 20 to 80 MPa, and

wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70 such that the cross section of the at least one longitudinal groove remains substantially constant when a radially outer surface of the tread band is in contact with the ground.

97. The pneumatic tire according to claim 96, wherein the modulus of elasticity under compression at 23°C of said second elastomeric material is about 4 to about 15 MPa.

98. The pneumatic tire according to claim 96, wherein the ratio between the modulus of elasticity under compression at 23°C of the first elastomeric material and the modulus of elasticity under compression at 23°C of the second elastomeric material of the tread band is not lower than about 1.30.

99. The pneumatic tire according to claim 98, wherein the ratio between the modulus of elasticity under compression at 23°C of the first elastomeric material and the modulus of elasticity under compression at 23°C of the second elastomeric material is about 1.5 to about 20.

100. The pneumatic tire according to claim 99, wherein the ratio between the modulus of elasticity under compression at 23°C of the first elastomeric material and the modulus of elasticity under compression at 23°C of the second elastomeric material is about 2.3 to about 7.

101. The pneumatic tire according to claim 96, wherein the IRHD hardness at 23°C of the first elastomeric material, measured according to standard ISO 48, is about 75 to about 95.

102. The pneumatic tire according to claim 96, wherein the IRHD hardness at 23°C of the second elastomeric material, measured according to standard ISO 48, is about 35 to about 80.

103. The pneumatic tire according to claim 96, wherein the tread band is provided with a plurality of longitudinal grooves and wherein said grooves are formed in respective first sectors, radially extending and axially spaced apart, substantially of said first elastomeric material.

104. The pneumatic tire according to claim 96, wherein said layer has a thickness of 1 to 5 mm.

105. The pneumatic tire according to claim 96, wherein the width of said at least one first sector is at least equal to the width of said at least one longitudinal groove.

106. The pneumatic tire according to claim 105, wherein the difference between the width of said at least one first sector and the width of said at least one longitudinal groove is 4 to 10 mm.

107. The pneumatic tire according to claim 96, wherein said at least one longitudinal groove is positioned astride the median plane of said at least one first sector.

108. A process for building a pneumatic tire comprising the steps of:

a) building a carcass structure having at least one carcass ply associated with at least one annular reinforcing structure;

b) assembling a belt structure;

c) arranging, at a radially outer position with respect to said belt structure, at least one radially extending first sector of a tread band, substantially of a

first elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C of 20 to 80 MPa, the at least one radially extending first sector defining a longitudinal groove having a cross section;

d) arranging, at a radially outer position with respect to said belt structure, a plurality of radially extending second sectors of the tread band, axially spaced apart and substantially of a second elastomeric material having, after vulcanization, a value of the modulus of elasticity under compression at 23°C lower than the value of the modulus of elasticity under compression at 23°C of said first elastomeric material; and

e) arranging, at a radially outer position with respect to said belt structure and a radially inner position with respect to said first and second sectors, an underlayer suitable for providing global rigidity to the tread band, the underlayer being integral with the first sector and comprised substantially of the first elastomeric material;

wherein said steps c) and d) are carried out in such a way that said second sectors are positioned at axially opposite sides of said at least one first sector, and

wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70 such that the cross section of the at least one longitudinal groove remains substantially constant when a radially outer surface of the tread band is in contact with the ground.

109. The process according to claim 108, wherein said belt structure is shaped on a substantially cylindrical auxiliary drum and wherein said steps c) and d) comprise the steps of:

f) positioning said auxiliary drum at a first delivery member of the first elastomeric material;

g) delivering by means of said first delivery member at least one elongated element made of said first elastomeric material at a radially outer position with respect to said belt structure while carrying out a relative displacement between the first delivery member and the auxiliary drum, so as to form said at least one first sector of the tread band;

h) positioning the auxiliary drum at a second delivery member of the second elastomeric material; and

i) delivering by means of said second delivery member at least one elongated element made of said second elastomeric material at a radially outer position with respect to said belt structure while carrying out a relative displacement between the second delivery member and the auxiliary drum so as to form said second sectors of the tread band axially spaced apart and positioned at opposite sides of said at least one first sector.

110. The process according to claim 109, wherein said steps g) and i) of delivering the elongated elements of said first and second elastomeric materials are carried out by rotating said auxiliary drum about its rotation axis.

111. The process according to claim 109, wherein the relative displacement between the delivery member and the auxiliary drum is carried out by imparting to the auxiliary drum a first translational movement along a direction substantially parallel to its rotation axis and/or a second translational movement along a direction substantially perpendicular to said axis.

112. The process according to claim 109, wherein said steps g) and i) of delivering the elongated elements of said first and second elastomeric materials are carried out by forming a plurality of coils axially arranged side-by-side and/or radially superposed to define said at least one first and said second sectors of the tread band.

113. The process according to claim 108, wherein said belt structure is assembled on a substantially toroidal support and wherein said steps c) and d) comprise the steps of:

e') positioning said substantially toroidal support at a first delivery member of the first elastomeric material;

f') delivering by means of said first delivery member at least one elongated element made of said first elastomeric material at a radially outer position with respect to said belt structure while carrying out a relative displacement between the first delivery member and the substantially toroidal support, so as to form said at least one first sector of the tread band;

g') positioning the substantially toroidal support at a second delivery member of the second elastomeric material; and

h') delivering by means of said second delivery member at least one elongated element made of said second elastomeric material at a radially outer position with respect to said belt structure while carrying out a relative displacement between the second delivery member and the substantially toroidal support, so as to form said second sectors of tread band axially spaced apart and positioned at axially opposite sides of said at least one first sector.

114. The process according to claim 113, wherein said steps f') and h') of delivering the elongated elements of said first and second elastomeric materials are carried out by rotating said substantially toroidal support about its rotation axis.

115. The process according to claim 113, wherein the relative displacement between the delivery member and the substantially toroidal support is carried out by imparting to the substantially toroidal support a first translational movement along a direction substantially parallel to its rotation axis and/or a second translational movement along a direction substantially perpendicular to said axis.

116. The process according to claim 113, wherein said steps f') and h') of delivering the elongated elements of said first and second elastomeric materials are carried out by forming a plurality of coils axially arranged side-by-side and/or radially superposed to define said at least one first and said second sectors of the tread band.

117. The process according to claim 113, wherein said substantially toroidal support is substantially rigid.

118. The process according to claim 108, wherein the underlayer has a thickness of 1 to 5 mm.

IX. Evidence Appendix

This Evidence Appendix includes Exhibit A, a paper by Alan G. Veith entitled "A Review of Important Factors Affecting Treadwear" ("the Veith paper"), which was presented at a meeting of the Rubber Division, American Chemical Society, in Toronto, Ontario, Canada, on May 21-24, 1991. The Veith paper was included as an attachment to the "Agenda for Examiner Interview" ("the interview agenda") submitted to the Examiner on May 18, 2011, for a telephone interview that took place on May 19, 2011. A copy of the interview agenda is attached as Exhibit B.

EXHIBIT A

"A Review of Important Factors Affecting Treadwear"
by Alan G. Veith
Presented May 21-24, 1991

A REVIEW OF IMPORTANT FACTORS AFFECTING TREADWEAR*

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CONTENTS

I. INTRODUCTION

Although treadwear is a complex phenomenon, substantial progress has been made in its understanding during the past 20 years. Gough and co-workers[1-3] who studied tire footprint mechanics, began their work in the late 1950's. The work of Schallamach, Grosch, and

* Based on a paper presented at a meeting of the Rubber Division, American Chemical Society, Toronto, Ontario, Canada, May 21–24, 1991. S.

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co-workers[4-6], who emphasized the study of laboratory abrasion in addition to tire testing, also began at approximately the same time.

The rate of wear depends upon the amount of frictional work generated in the interface between the tire and road. The frictional work raises the temperature in both layers of the interface in complex temperature distribution patterns. The properties of the two interface materials, the rubber and the road, are not constant as the treadwear environment changes week to week, and season to season.

A very simple model is presented that describes the mechanical action of a "typical" tread element. This is used in conjunction with a simple wear equation that acts as an organizational aid to partition the various factors that influence treadwear into one of two categories, (1) "abradability" or (2) "frictional energy." Each of the factors in both of these categories is discussed; some of these factors are interactive, and the known interactions of this sort are outlined.

The most complex component of the overall treadwear process is the "loss mechanism," the detailed frictional interface "physical–chemical action" that removes rubber from the tire. The mechanisms that have been well documented are discussed, and sufficient background is given to enable the reader to better understand the influence of material properties and environmental factors on the "loss mechanisms."

II. BASIC MECHANICS OF TREADWEAR

As a tire performs its functions of providing for vehicle control (lateral, longitudinal, and cornering forces) and cushioning the vehicle from the shock forces of road irregularities, each surface area element of the tread undergoes a tire footprint (interface) mechanical action that generates frictional work along with heat and temperature. The result is wear or abrasion. Figure 1 indicates the simplified mechanics of the passage of a typical tread element over a surface. It is shown in isolation for simplicity.

There are four important stages in moving through the footprint. In Stage 1 the element approaches the pavement (as the tire rotates and moves forward). In Stage 2 the element makes contact and becomes "frictionally adhered" to the pavement. The two small crosses in the diagram indicate element midpoint register marks. As the tire continues to roll forward, the location of the element with respect to the center of tire rotation changes; this distance first decreases and then increases as the element moves (backward) through the footprint. In this movement, a lateral or longitudinal (or combined) tangential force (F_T) arises at the interface due to tire forces generated by the vehicle trajectory. At some point, the "frictional adhesion" of the element to the pavement cannot continue to restrain the element in its initial adhered position and a slip or sliding motion occurs, indicated by dl. Friction work or energy, F_E, is generated by this action and is given by Equation (1):

$$F_E = \int F_T * dl. \quad (1)$$

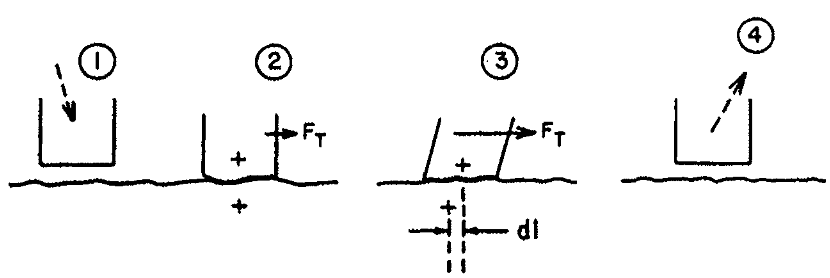

FIG. 1.—Simplified tread-element contact mechanics.

F_E is the integral of $F_T dl$ but the simple product of the force times the distance is assumed for simplicity. Stage 3, the completion of the sliding, occurs near the exit of the footprint, and the element leaves the footprint as indicated by stage 4.

All treadwear is produced by this simplified model process. In simple straight rolling, F_T and dl are small in magnitude. As vehicle maneuvers of increased acceleration occur, the magnitudes of both F_T and dl increase. Part of the frictional work ends up as heat, and part is used in the actual physical rupture and removal of rubber in the abrasion process.

A. SIMPLE WEAR EQUATION

Based upon the direct proportionality of wear and frictional energy, proposed by a number of investigators[1,4,5], the simplest equation that relates treadwear and frictional work is

$$R_w = A * F_E, \tag{2}$$

where R_w = rate of wear, amount of rubber lost from a unit of tread surface per tire revolution; A = abradability = the amount of rubber lost in a tire revolution per unit area per unit frictional work under specified interface conditions; and F_E = the frictional work or energy per unit area, per revolution, for a typical tread element.

The abradability, A, is not a material constant, it is a function of the rubber, the pavement, the temperature (at the interface) and interfacial contaminants. The lack of a constant material value for A limits the usefulness of Equation (2) as an aid in directly solving treadwear problems; it does have an important role in organizing thinking in the analysis of treadwear problems.

This is illustrated in the block diagram of Figure 2. Factors that contribute to A are shown on the left. Each "A-factor" operates through its influence on a loss mechanism. Factors that contribute to frictional work are indicated on the right. Without differentiation between abradability factors and frictional work factors, discussion of treadwear tends to be confused. All abradability factors are essentially independent of frictional work factors except tire

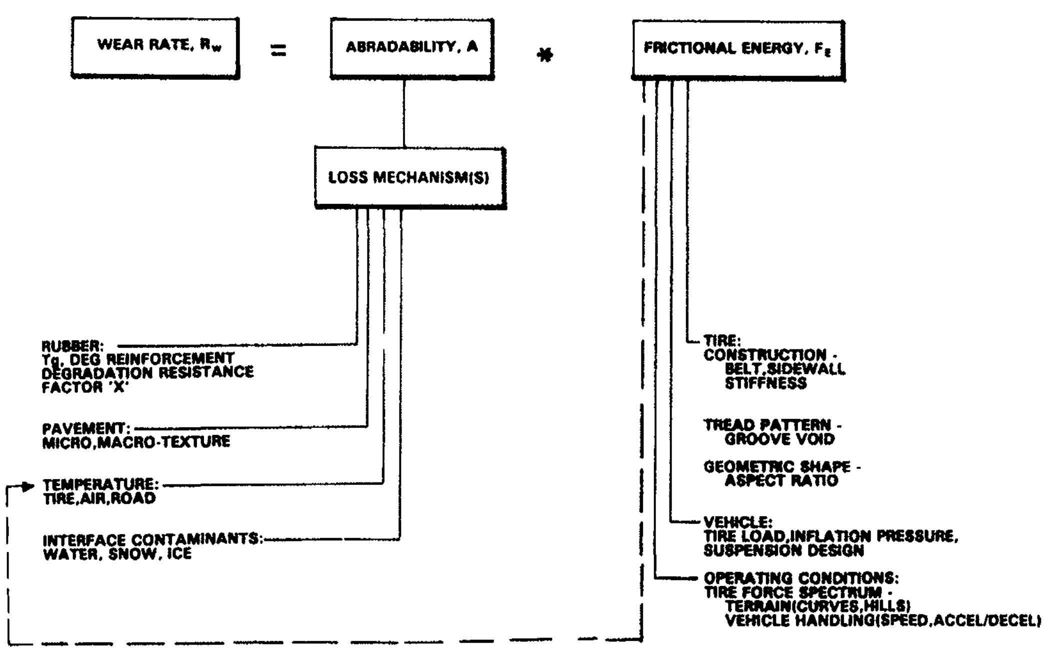

FIG. 2.—Block diagram of simple wear equation.

interface temperature. All frictional work factors influence the tire interface temperature since any change in a right hand "F_E factor" increases the expended interface energy, raising the transient sliding temperature. The dashed line indicates this interaction. Therefore, an increase in frictional work increases interface temperature in addition to other direct consequences of increased frictional work.

Using the model as depicted in Figure 1 and the wear equation, several key factors that are important to tire treadwear performance are given in Table I.

All of these factors will be taken up individually and then an attempt will be made to show how they relate to each other. The influence of the factors is evaluated under certain levels of tire "severity." Severity is a generic term that describes the test or use conditions. Typical high severity is hot weather, high speed, intense cornering vehicle operation on an abrasive pavement. Typical low severity is cool weather, moderate speed vehicle operation on straight highways in a flat terrain rural area.

III. FRICTIONAL ENERGY FACTORS—I

A. TIRE CONSTRUCTION FACTORS

Figure 2 indicates that tire construction features primarily influence the amount of frictional work. Construction factors do not include tread material variations. To review tire construction factors, we turn to a very comprehensive treadwear program conducted under the auspices of The Rubber Manufacturers Association (RMA) in the late 1970's as part of an industry effort at alternative approaches to the treaawear testing of Uniform Tire Quality Grading (UTQG) mandated by the National Highway Traffic & Safety Administration[7].

Although the goal of the RMA program was not achieved, the testing produced valuable insight to treadwear performance. This program evaluated the influence of generic tire type, *i.e.*, radial, belted-bias, bias (R, BB, B), aspect ratio (60, 70, 78), tread pattern groove void level, type of pattern (straight grooves *vs.* block designs), and two different tread compounds. These five variables (or factors) were evaluated for their influence on treadwear in a statistical design test program at the Laredo Proving Grounds (Laredo, Texas), at two treadwear severity levels; *i.e.*, at two overall rates of wear. These two are designated LPG-1 and LPG-2. Twenty-eight separate tire constructions were used. The word construction implies a tire with certain selected levels for all five of the variables.

The five independent variables were assigned values for their low, intermediate, and high levels; see Table II. The tread property (loss modulus) was selected to represent the two compounds described in Table III. This characteristic was used because it was the most distinctive physical property of the two compounds that reflected the different degrees of

TABLE I

IMPORTANT TREADWEAR FACTORS

1. Tire construction
   i) generic type (radial, belted-bias, bias)
   ii) tread pattern (groove void) features
   iii) geometric shape or aspect ratio
   iv) tire mechanical model
2. Tread materials
   i) type of rubber (T_g, other properties)
   ii) degree of reinforcement (black type, content)
   iii) crosslink structure/degradation resistance
3. Environmental
   i) ambient (air, pavement, tire) temperature
   ii) seasonal and short-term weather effects (rainfall, etc.)

TABLE II

RMA PROGRAM—INDEPENDENT VARIABLE LEVEL ASSIGNMENT

Variable	Level of variable		
	Low	Intermediate	High
1. Generic type (GT)	−1 (bias)	0 (belted-bias)	+1 (radial)
2. Aspect ratio (AR)[a]	60	70	78
3. Groove void fraction (ϕ_v)[b]	0.16	—	0.43
4. Pattern type (PT)	−1 (circum grooves)	—	+1 (block)
5. Tread property (Loss modulus, E'')	0.84	—	1.37

[a] AR = ratio of the tire section height to the tire section width (×100).

[b] ϕ_v = the ratio of the void volume of all grooves to the volume of an annular treadband whose cross-section is the product of the contact width (of the tread) in mm and a reference radial distance (or depth) of 10 mm.

reinforcement, *i.e.*, level and type of carbon black. As the discussion in succeeding sections of this review on tread compound properties will show, no claim can be made that treadwear is solely related to loss modulus.

B. TEST RESULTS—RMA PROGRAM

The basic treadwear data are given in an earlier series of papers[7]. This section gives a brief summary of the multiple regression analysis of the treadwear data which in turn gives an empirical model (equation) containing terms for GT, AR, ϕ_V, and E''. Figures 3–6 illustrate the influence of each of these four variables. The graphs are generated as "calculated lines" from the model equation. The influence of generic type is illustrated in Figure 3. Rate of wear values are shown for the 3 qualitative levels; −1 (Bias), 0 (Belted-Bias), and +1 (Radial). For this plot and Figures 4 to 6, the other variables are fixed as indicated on the legend. The plot demonstrates the enhanced beneficial effect of a radial tire as severity is increased, *i.e.*, treadwear is increased less for a radial tire in moving from the low severity, LPG-1, to the high severity, LPG-2, compared to the same change in severity for a bias tire.

TABLE III

MAIN COMPONENTS IN THE FORMULATIONS FOR COMPOUNDS 3 AND 8 OF THE RMA PROGRAM

Compound 3[a]	Compound 8[a]
SBR 65	SBR 65
BR 35	BR 35
N330[b] 65	N220[b] 75
Oil 40	Oil 40

[a] Loss modulus: Compound 3 = 0.84 MPa; Compound 8 = 1.37 MPa.

[b] N330 is a carbon black with lower structure and larger particle size than N220, *i.e.*, N330 is less reinforcing than N220.

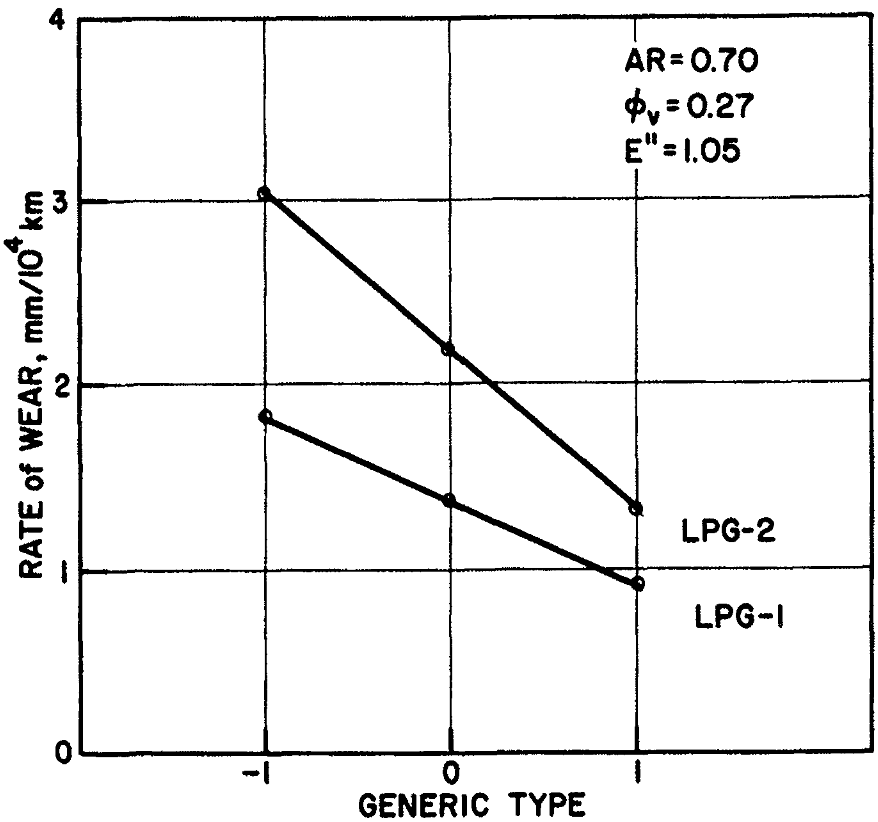

FIG. 3.—Rate of wear as a function of tire generic type (interaction model).

Figure 4 shows how wear rate increases as aspect ratio is increased. Again the slope is different for the two courses, LPG-1 and LPG-2. The influence of groove void fraction is illustrated in Figure 5. Parallel behavior for wear rate *vs.* void fraction is observed for either LPG-1 or LPG-2 and for radial *vs.* bias construction. Finally, the influence of increased loss modulus is shown in Figure 6. A moderate rate of wear-rate reduction is observed as E'' increases with the same parallel behavior as in Figure 5.

To put the relative influence of the 5 variables into an appropriate perspective, a sensitivity analysis was conducted. The regression coefficients for each of the 5 variables were expressed in standardized format and normalized by assigning the variable with the largest standardized regression coefficient a value of 100 and expressing the remaining 4 variables as a percentage. Table IV illustrates the resulting order; $GT >$ groove void $> AR > E'' > PT$. The (−) symbol in Table IV indicates that an increase of that variable decreases wear rate.

The detailed analysis showed that treadwear performance is influenced by some variable interactions. This variation in treadwear performance due to the interaction of generic type, aspect ratio, and groove void volume can be summarized by some generalizations about tire design decisions to attain maximum tread life. For a more detailed discussion, see the original series of papers[7].

1. More attention must be given to selecting an appropriate aspect ratio for bias tires than for radial tires. Bias tires require lower aspect ratios to obtain the maximum treadlife potential.

2. Bias tires require decreased groove void volume (compared to radials) to obtain the increased treadlife that is potentially attainable in a bias tire.

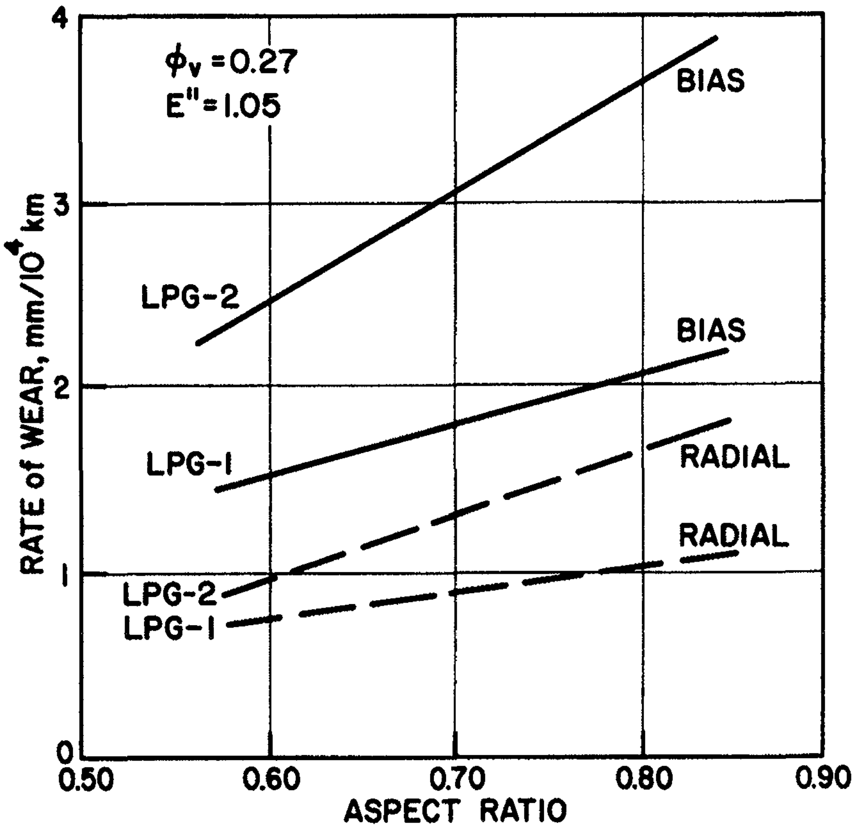

FIG. 4.—Rate of wear as a function of tire aspect ratio (interaction model).

3. As the general severity of wear increases, the influence of aspect ratio, groove void volume, and generic type on treadwear, increases.

C. TIRE MECHANICAL PROPERTIES *VS.* TREADWEAR

The influence of generic type and aspect ratio can be put on a more quantitative basis by the use of mechanical theories of tire operation. This also aids in explaining the observed performance in the RMA program. Gough[2,3] did pioneering work on modelling the mechanical properties of tires. He considered the tire as a beam on an elastic foundation. The beam is the treadband and the carcass is the elastic foundation. Gough maintained that for high treadwear resistance, a tire should have a rigid, high-modulus treadband and a high compliance or low-spring-rate carcass. Figure 7 illustrates a simple model of a tire based on these concepts. The important mechanical properties of the treadband and carcass are indicated.

The stiffness of a beam may be expressed by its flexular rigidity, defined for simple beams as the product of Young's modulus, E, and cross-sectional area moment of inertia, I. If a simple (slender) beam is deflected by the application of a force F at the midpoint between two points of restraint as shown in Figure 8, the EI product can be determined by

$$EI = FL^3/48d. \qquad (3)$$

I is given by $bh^3/12$; where h is the beam thickness (in the direction of bending); b is the width; d is the deflection; and L is the spacing of the restraint points.

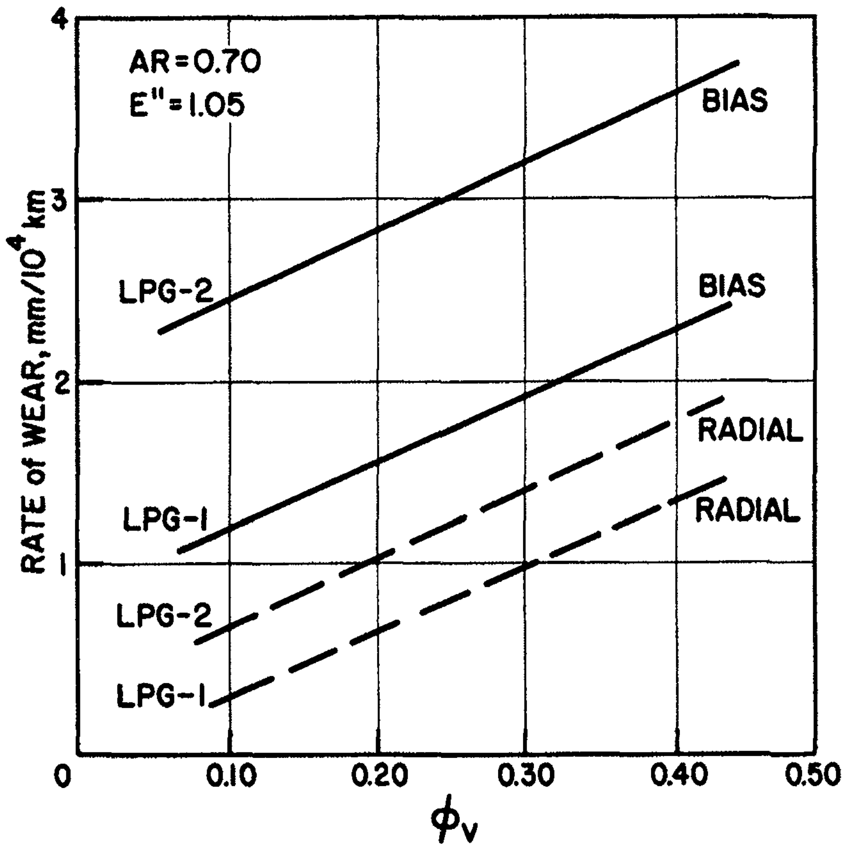

FIG. 5.—Rate of wear as a function of groove void-volume fraction (interaction model).

Gough used EI values measured on treadband slabs and a carcass spring rate K, to calculate the ratio of EI/K. He established a linear correlation between this ratio and a term Gough developed called the cornering coefficiency, CE. Using Gough's notation,

$$CE = (F_Y \sin \delta)/W_F, \tag{4}$$

where F_y = lateral force, δ = slip angle, W_F = frictional work per unit area or width of footprint, per unit forward movement of the element in the contact patch.

Cornering efficiency is high when cornering forces are developed with minimal frictional work or tread element slippage in the contact patch. When cornering efficiency is high, treadlife is high. Later, Gough realized that in addition to a high Young's modulus, E, another term, the shear modulus, G, is an important mechanical property of the belt or treadband. Modern composite theory of materials as discussed by Walter *et al.*[8], was not developed at the time Gough did his first work, but it can be used to calculate "stiffness parameters" in various directions in tire belts—anisotropic composites of textiles and rubber—and these parameters can be related to the stiffnesses that Gough discussed and measured.

A device, described more fully in Part IV of Reference 7, was constructed to measure the two important stiffness characteristics of tires; the tread band edgewise bending stiffness and the carcass stiffness. Figure 9 illustrates the concept of the curved beam (the treadband) and how it is deflected by the application of a point force.

If restraints a and b are in place, the force–deflection data can be used to assess beam stiffness. If restraints a and b are removed, the treadband moves essentially as a unit upon

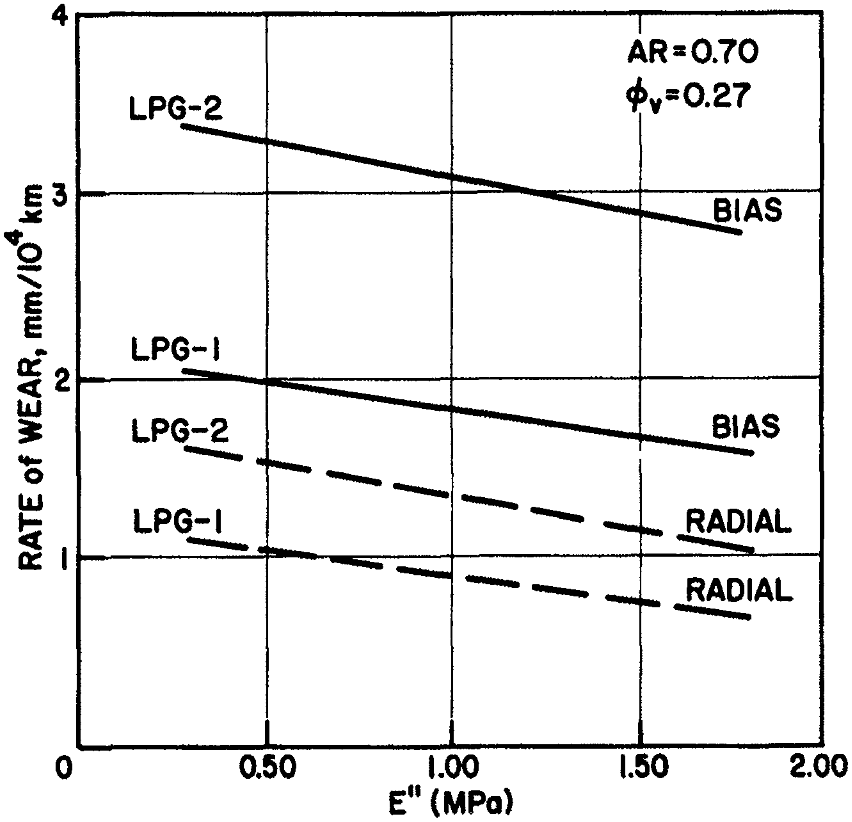

FIG. 6.—Rate of wear as a function of tread loss modulus E'' (interaction model).

force application and the stiffness of the foundation springs or carcass is measured provided that the force, F, is appropriately applied.

A correlation between the ratio of the two measured deflection stiffnesses (K_B^0, the treadband edgewise bending stiffness, and K_c, the carcass lateral deflection stiffness) was conducted using data from the RMA program. Tires with similar tread patterns and with the same tread compound were selected for these mechanical property measurements. Table V gives these constructions, the two stiffnesses, their ratio, and normalized treadlife values for LPG-1 and LPG-2. All treadlife values were normalized to equal groove void.

Figure 10 illustrates plots of normalized treadlife *vs.* the stiffness ratio for LPG-1 and LPG-2. The significance of the relationships is indicated by the correlation coefficients (0.97, 0.96). Note in Table V that for any generic type (R, BB, B), the treadband stiffness, K_B^0, is

TABLE IV

RELATIVE IMPORTANCE OF FIVE VARIABLES FOR INFLUENCE ON TREADWEAR

Variable	Std. regression coeff.	Rank, order of importance
Generic type	−0.74	100
Groove void	0.34	46
Aspect ratio	0.29	39
Loss modulus, E''	−0.11	15
Pattern type	0.05	7

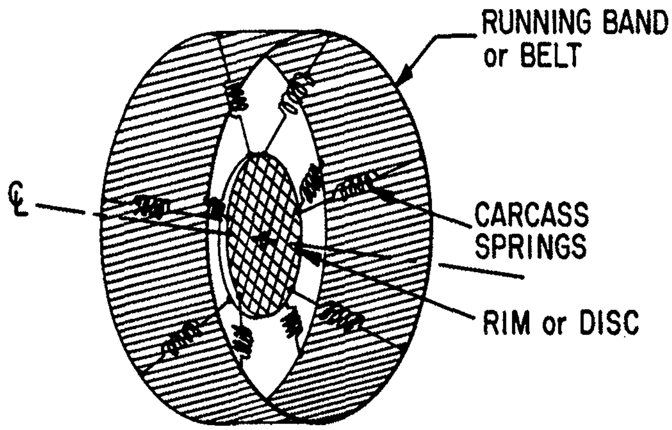

FIG. 7.—Simple tire mechanical model—treadband defined by circumferential (hoop) stiffness and transverse (edgewise) bending stiffness and carcass defined by elastic spring stiffness.

greater for the lower aspect ratio; also note the lower carcass stiffness values for radial tires compared to bias or belted-bias tires. The two stiffness parameters K_B^o and K_C may be considered as good first-order indicators of treadwear perfbrmance. Certain secondary factors, not taken into account, also play a role in treadwear performance (tread radius and some other internal construction features). The two stiffnesses are parameters that encompass both gross structural differences (*i.e.*, radial *vs.* bias) and aspect-ratio differences as well as such factors as belt angles and the shear moduli of the belt coat compounds.

The observed treadwear performance of the RMA program may be explained on the basis of the Gough tire model and Equation (1). Radial tires perform better than bias tires because the rigid belt and more compliant carcass postpone the onset and decrease the magnitude of sliding (Figure 1, stage 3) for tread elements, thus resulting in less frictional work for any level of gross tire force. The rigid belt maintains shear stability (less sliding) of the elements. A low groove void tire also possesses increased tread-element shear stability so stage 3 sliding is decreased. A low-aspect-ratio tire is more rigid laterally than a high-aspect-

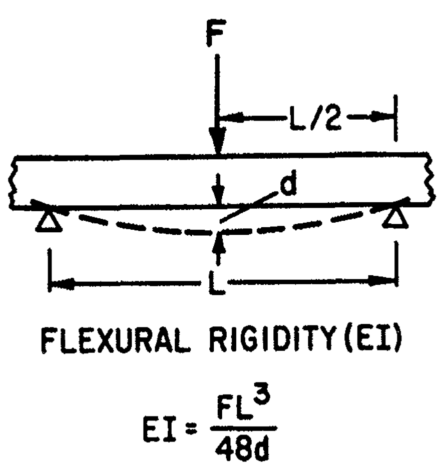

FIG. 8.—Beam bending mechanics.

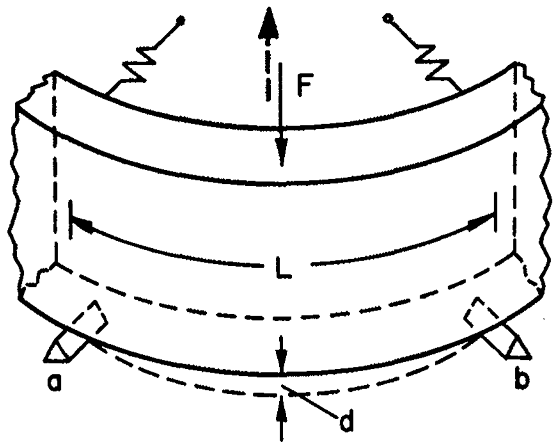

FIG. 9.—Treadband edgewise bending (curved beam model).

ratio tire, and this also yields less stage 3 sliding in cornering, the predominant vehicle action responsible for wear.

IV. FRICTIONAL ENERGY FACTORS—II

The two remaining frictional energy categories "Vehicle" and "Operating Factors" mentioned in Figure 2, will be considered next. These two categories are highly related and interactive.

A. TIRE LOAD

In general, increased tire loads lead to increased wear. The magnitude is a function of the operating terrain and the way the vehicle is handled, *i.e.*, speed and cornering conditions.

TABLE V

TIRE FEATURES, STIFFNESS AND TREADLIFE DATA—RMA PROGRAM

Const number	K_B^o [a]	K_c [a]	K_B^o/K_c	*TL* @ LPG1	*TL* @ LPG2
1 (B60)	221	120	1.84	63	35
2 (R78)	316	86	3.68	106	74
5 (R60)	440	81	5.40	204	142
6 (B78)	89	127	0.70	50	27
17 (BB60)	264	109	2.42	108	76
18 (BB78)	147	110	1.34	72	39
21 (R70)	259	79	3.29	138	93
22 (R70)	168	100	1.68	76	43
29 (B78)	89	127	0.70	60	34
31 (B60)	221	120	1.84	92	50
33 (R78)	316	86	3.68	132	79
35 (R60)	440	81	5.40	185	118

[a] K_B^o and K_c in kN/m, were measured under special conditions, see Reference 7.
[b] TL = Treadlife in km (divided by 1000), normalized to a groove void fraction of 0.20; (treadlife projected from rate-of-wear data).

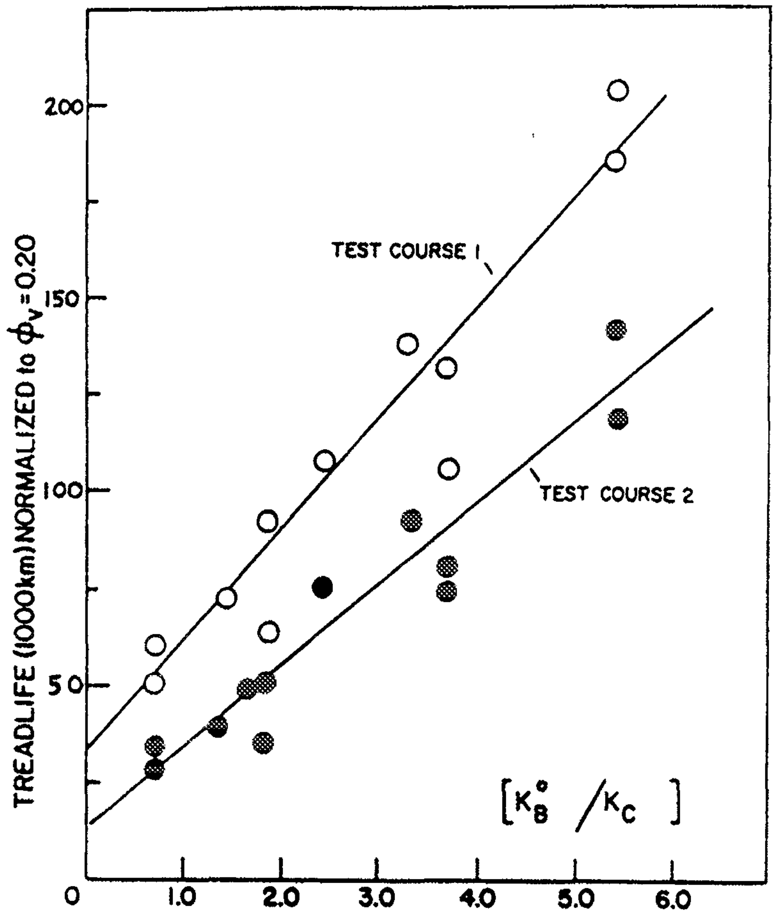

FIG. 10.—Normalized treadlife *vs.* stiffness ratio, K_B^o/K_C; test courses 1 and 2 = LPG-1 and 2 (corr. coeff. = 0.97 and 0.96, respectively).

This is demonstrated by comparing results obtained for accelerated treadwear tests conducted with a cornering trailer[9]. This type of test is conducted by imposing cyclic (toe-in, toe-out) slip angles (0.5 to 2° range) on a pair of tires and towing the trailer in a rectilinear manner on public highways with minimal curves and bends; this simulates vehicle operation over a range of cornering intensities. The effect of tire load on trailer wear rate is quite important, for it brings out an important distinction between trailer testing and regular vehicle convoy tests and/or vehicle operation. Tests[9] conducted in the load range of 4500–5800 N at (±) 1° slip angle indicated that trailer wear rate was increased by 4 percent per 450 N increase in tire load. The source of this relatively small magnitude effect lies in the mechanics of lateral force generation at small slip angles (0–2°). Investigators[1,10] have shown experimentally that, at 1° slip, lateral force changes very little with tire load in the rated load region. Values estimated from a publication by Gough[3] give a linear increase of approximately 2 percent per 450 N increased in the 4500 N load region. Since tire wear varies as the square of lateral force (see subsequent development of this concept in Section IV E), a 2 percent increase in lateral force yields a 4 percent increase in wear rate, the observed value. The important point is that the cornering forces tires develop in trailer operation are sustained dynamic equilibrium forces; the left tire balances the right tire. In vehicle maneuvers, how-

ever, a different force balance exists; the tire lateral forces are transient forces that balance the inertial centrifugal forces generated according to:

$$F = ma, \tag{5}$$

where F = force acting on all tires, m = mass of vehicle, and a = acceleration.

A tire load increase from 4500 to 4950 N will increase trailer tire wear rate by the aforementioned 4 percent. In actual vehicle operation, the increased mass of the vehicle, equal to this load change per tire, will increase wear rate in a vehicle cornering maneuver by the ratio, $(4950)^2/(4500)^2 = 1.21$, or a 21 percent increase. This is over five times the increase for trailer tests. Thus, tire load is an extremely important variable in vehicle tests—second only to vehicle velocities in fixed radius cornering.

The equations given in Section IV E show that wear rate varies as the fourth power of velocity. Tests carried out at different trailer speeds show that speed has a very slight effect on wear rate, comparable in magnitude to that of load. This is consistent with the virtual speed independence of lateral force and moment data[10]. Speed, or towing velocity in trailer testing, mainly influences the temperatures generated in the distorted carcass and tread at the tire–pavement interface. Speed, in vehicle tire-wear testing which has substantial cornering, determines in a very critical way tire forces which are inertial in origin. The distinction between the two must be kept clear.

B. INFLATION PRESSURE

The influence of inflation pressure on treadwear is not straightforward. Lowered inflation pressure: (1), reduces the cornering power (force per degree of slip angle); (2), at constant load, increases tire deflection as well as changes the interface pressure distribution in the footprint; (3), increases total footprint area; and (4), increases the hysteretically induced equilibrium running temperature. The net effect of all of these can be complex. Table VI gives results obtained for two different commercial radial tires with the same load rating and tread compound, but different tread patterns, aspect ratio, and construction (belt, carcass) features. They were tested in typical convoy procedures on test routes with varying cornering intensity.

Part of the complex behavior is due to varying magnitudes of crown-to-shoulder wear for the two tires and how the inflation-pressure cornering-intensity interaction influences this distribution of crown-to-shoulder wear.

C. SUSPENSION EFFECTS

The type of vehicle suspension determines the amount of camber angle a tire experiences during cornering. (Camber angle, is the angle of the wheel plane with respect to the horizontal ground plane.) This dynamic camber derives mainly from lateral weight transfer. Vehicles that have independent front suspension allow more camber than solid axle rear suspension types, and this difference is manifested in the wear patterns found on front and rear tires. Front tires quite frequently show more wear in the shoulder region than in the crown.

TABLE VI

PERCENT CHANGE IN OVERALL WEAR RATE FOR A 200 kPa DECREASE IN TIRE INFLATION PRESSURE[a]

Tire	High intensity cornering	Low/moderate cornering
A (HR78 × 15)	67	50
B (HR70 × 15)	12	32

[a] Inflation pressure reduced from 300 kPa to 100 kPa.

Other suspension characteristics that influence treadwear are the amount of "static" toe-in and camber specified by the vehicle manufacturer. Toe-in is a specified intentional small slip angle to give acceptable handling and linear tracking behavior. Preset nonzero camber settings also influence dynamic handling. Toe-in and camber effects frequently interact with wheel torque magnitudes to produce complex wear patterns on tires called "irregular" wear.

The rear tires of front wheel drive (FWD) vehicles frequently show tendencies toward irregular wear. Shepherd[11] recently reported on this problem. Using a simple sliding abrasion model for the tread elements, he showed how certain combinations of toe-in and camber (*ca.* 1°) on the rear tires of FWD vehicles could induce a condition called "diagonal wear." Figure 11 illustrates this type of irregular wear which characteristically appears on tires that are wearing at a low rate, where the intensity of inertial forces from cornering is low. The rear tires on FWD vehicles run at low loads (approximately at 50% of rated load); they do not generate high lateral forces due to their vehicle location and the low load.

D. FRONT-WHEEL *VS.* REAR-WHEEL DRIVE

With the worldwide increase of front-wheel drive (FWD) vehicles, the matter of tire wear on such vehicles, compared to rear-wheel drive (RWD) vehicles, takes on added importance. Kondo and Brenner[12] published a brief paper on this in 1971. Typical convoy tests on comparable vehicles (size, power) were conducted on a Nevada course which included hills and curves. Veith[13] analyzed their treadwear data and arrived at the following conclusions.

1. The front-axle to rear-axle wear rate ratio was 2.27 for FWD vehicles; compared a 1.07 ratio for RWD vehicles.

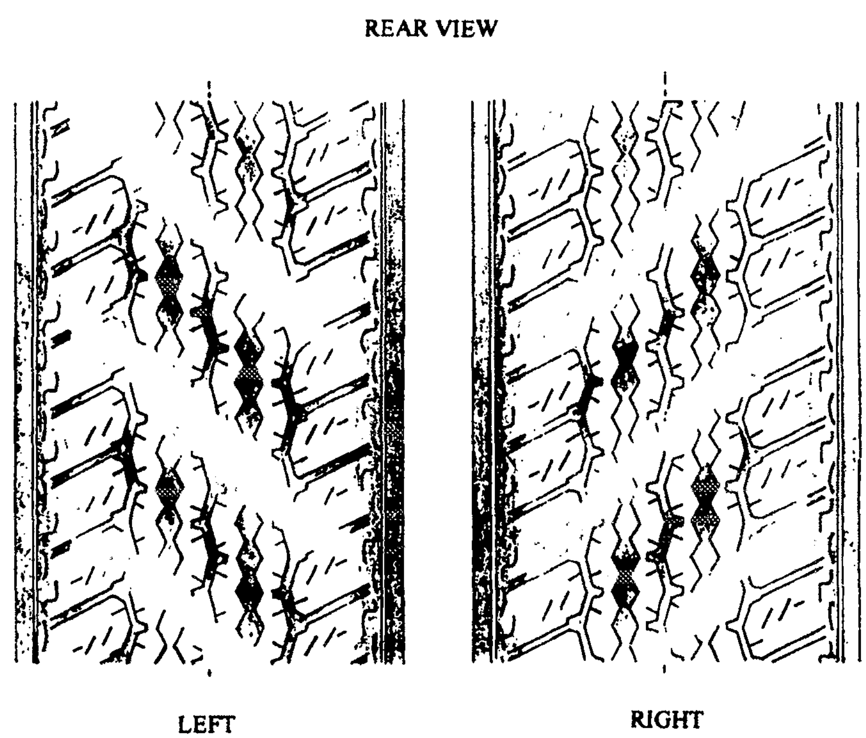

FIG. 11.—Illustration of tire diagonal wear, taken from Shepherd[11].

2. The average wear rates (front and rear) of both vehicles were almost equivalent with a FWD/RWD ratio of 1.08, *i.e.*, FWD vehicle average wear rate is about 8% greater.

3. The variability of the wear rate from test-period-to-test-period is greater both in an absolute sense and in a relative sense, for front wheel axles, by a 1.50 ratio.

The tires on front axles of FWD vehicles wear at a faster rate compared to similar tires on RWD vehicles, since they must propel the vehicle in addition to generating the greater part of the cornering force for lateral control. They also are more heavily loaded. In RWD vehicles, although the rear tires are less heavily loaded than the front and generate a smaller lateral force in cornering, they propel the vehicle and thus experience increased frictional work. The increase in absolute test-period-to-test-period variability is a function of the severity of frictional work that the tire (in its position) experiences; front tires on a FWD vehicle have the greatest variability, whereas rear tires on a FWD vehicle have the least.

E. TIRE FORCES—THEIR IMPORTANCE IN TREADWEAR

We may now bring together the important factors of tire load, vehicle speed, and cornering turn-radius, and relate them to the tire force distribution in vehicle use. Of the factors listed on the right hand side of Figure 2, the most important is tire force. Several investigators have illustrated the relationship between tire wear and tire forces[2,4,5,9]. The most important forces originate from the inertia of the vehicle when there is a change in magnitude or direction of velocity. These longitudinal and lateral forces are balanced by tractive forces in the contact area and produce interfacial tire contact stresses, frictional work, and wear.

Most of the literature work has dealt with the influence of lateral or cornering forces because these have been shown to be more important than longitudinal forces and more prevalent in normal vehicle use[9]. Such investigations have demonstrated that the dependence of wear rate on lateral force is a power function as described by the following general equation:

$$R_w = KF^n, \tag{6}$$

where R_w is the wear rate in mm/10 000 km, F is the tire force in N, K is a constant, and n is an exponent, usually between 2 and 4.

The exponent n is found to be approximately 2 for many pavements. In general, abrasive pavements (high microtexture) yield values near 2, while blunt-asperity pavements with low microtexture, yield values in the 2.5–3.5 range.

A simplified development of the dynamics of vehicle cornering is as follows: Most lateral maneuvers consist of traveling a certain path distance at some velocity and turn radius. The relative wear per unit path distance can be developed using a wear equation exponent of two. If the curve radius is, R, the velocity, V, and the vehicle mass is M, the tire-pavement force relation is

$$F^* = Ma; \tag{7}$$

where F^* = lateral force generated by all four tires, and a = centripetal acceleration. The force in gravitational units is

$$F = WV^2/RG = Wg; \tag{8}$$

where, F = total vehicle lateral force, N,

W = vehicle weight, N,

G = acceleration constant, 9.8 m/s^2,

R = curve radius, m,

V = velocity, m/s,

and, $$g = (V^2/R)\cdot 1/G. \tag{9}$$

Thus, g is the acceleration expressed in dimensionless units relative to G. The term, g, also has a second definition, *i.e.*, the ratio of the tangential (lateral or longitudinal) force to the normal force for a tire, where normal force is the tire load. The relation between the rate of wear and the variables of the situation can be developed on the basis of Equation (6) with R_w expressing this rate; *i.e.*

$$R_w = KW^2V^4/R^2G^2 = KW^2g^2 \tag{10}$$

Thus the wear rate depends upon the variables of the situation as follows:

(vehicle weight)^2, with R and V constant;
(vehicle velocity)^4, with R and W constant;
(inverse radius)^2, with V and W constant.

F. QUANTIFYING TREADWEAR *VS.* TIRE-FORCE DISTRIBUTION

The paramount importance of tire force on treadwear prompted the development of a way to quantify this treadwear factor, especially with respect to the normal convoy testing procedures used for tire evaluation. Veith[14] developed a device called a "Driving Severity Monitor" to characterize the route-vehicle-driver system used in treadwear testing. The monitor utilizes recorded values of lateral (and longitudinal) acceleration and velocity (once per revolution) plus traveled distance to calculate a special single value called a "Driving Severity Number," DSN, that characterizes the route-vehicle-driver system for its tire force severity during any journey. The DSN is based upon the sum of special distributed calculated wear rates and not on average g or speed values which were shown to be nondefinitive parameters for route-vehicle-driver characterization. Figure 12 illustrates how wear rates for tires in the RMA program (two types, two aspect ratios) correlate with the measured DSN for four test courses.

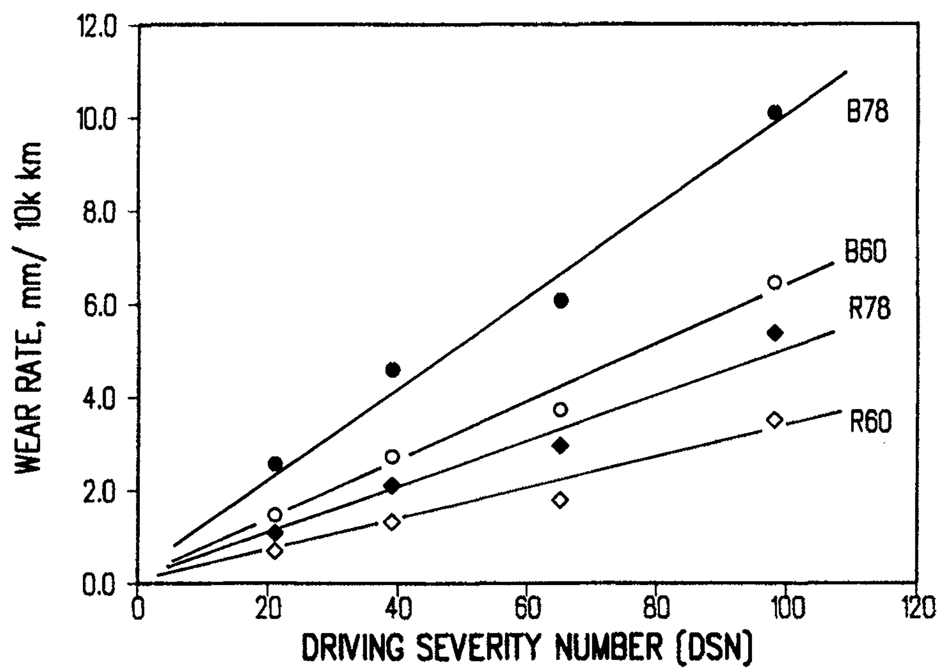

FIG. 12.—Rate of wear at Automotive Proving Grounds *vs.* Driving Severity Number (DSN), for four types of tires; R = radial, B = bias, 60, 78 = aspect ratios.

The use of this "monitor" system permits the quantification and control of regular treadwear testing procedures to a substantial degree, since it responds to all three components. Vehicles and test routes can be well quantified and controlled to a degree, but the varying handling patterns of different drivers at different times have always been a large contributor to the observed variation in treadwear test results.

V. ABRADABILITY—LOSS MECHANISMS

Prior to discussing tire treadwear performance from the viewpoint of abradability, wear or loss mechanisms must be discussed. A quick review of generalized wear concepts is presented along with a brief discussion of theories of friction. Laboratory wear testing is also discussed along with its role in determining wear mechanisms.

A. WEAR AND FRICTION OF MATERIALS

When a broad range of materials is considered (metals, plastics, etc.), wear may be classified as:

1. Adhesive Wear—removal of material caused by high transient adhesion ("welding") of asperities.
2. Abrasive Wear—caused by a cutting-rupture action of sharp angular asperities on the sliding counterface or as third bodies (particles).
3. Erosive Wear—cutting-rupture action of particles in a liquid (fluid) stream;
4. Corrosive Wear—from direct chemical surface attack.
5. Fatigue Wear—caused by rapid or gradual material property changes that give rise to cracks and with their growth, a loss of material.

This list of wear mechanisms is usually compiled with "brittle *vs.* ductile" materials in mind where the surface-asperity deformations are mainly of a plastic-flow character. Some elastic deformation obviously exists, but it very frequently plays a minor role in the wear mechanism. Practical wear situations rarely involve only one of these mechanisms; a two or three way combination is frequently encountered.

Briscoe[15], in reviewing wear, adopted the concept of "cohesive" wear, controlled by the rupture strength or energy (toughness) of the wearing material. In this scheme, a second type of wear is defined as "interfacial wear," *i.e.*, high levels of frictional energy dissipation in very thin surface layers. High transient temperature increases are characteristic of this type of wear. Abrasive and fatigue wear (2 and 5 in the above list) are typical examples of cohesive wear; corrosive and possibly adhesive wear (4 and 1) are examples of interfacial wear as defined by Briscoe.

Rubber, used as a generic term for a broad range of polymers that possess the unique characteristic of a high level of elastic responses to applied stress, occupies a unique role in tribology. Elastic response implies that most of the energy input is returned on release of the applied stress. Under nonabrasive conditions, rubber friction is a composite of two mechanisms, adhesion and deformation. The deformation mechanism which plays a strong role in tire traction performance will not be discussed. The adhesion component is attributed to a bonding of surface atoms between sliding members, the breaking of which requires work. The energy lost in breaking adhesive bonds is assumed to be not fully compensated for by the energy gained upon remaking them. It is the detail of the dissipation process that presents great difficulties in all adhesion theories of rubber friction. Several reviews of these theories have appeared[6,16–18]. The theories can be classified as either molecular or macroscopic, and one of the reviews[16] shows that they all contain a viscoelastic loss factor.

Macroscopic theories are based on different ideas. Savkoor[19] proposed that rubber adhered to the track in domains containing a number of bonds, each domain being able to indefinitely sustain a small but finite force because of an equilibrium between the breaking and making of bonds within the domain. This ensured the existence of static friction.

Tabor and Ludema[20] assume that interface adhesion is so strong that tearing takes place in a rubber layer about 10 nm from the interface. Using tensile strength data of rubber (as

a function of temperature and rate), they deduced an effective tear strength of the interface. The product of these data gave the shear strength of the interface as a function of speed, which agreed with observation. Kummer[21] has attempted to combine molecular and macroscopic descriptions of adhesional friction into a unified theory. Adhesion is attributed to electrostatic attraction between rubber and track.

After 35 years, the debate continues on the mechanism of rubber friction. The theories described have largely ignored the nature of the counterface, the exact location of interface sliding, and the possible consequence of strain crystallization of rubber molecules close to the interface. Schallamach described an optical study of the contact of a rubber hemisphere sliding on transparent surfaces[22]. For soft rubber sliding over a smooth, hard clean counterface, relative motion between the two surfaces was due to "waves of detachment." The waves moved as folds across the rubber surface in the direction of sliding. Schallamach associated them with tangential and compressive stress gradients and the resulting elastic instability or buckling. Between these waves, there was strong adhesion. The waves are called Schallamach waves.

Since the original description, several workers have continued this line of investigation. Kendall[23] showed that, for the rolling friction of smooth cylinders over smooth soft rubber, the retarding force could be accounted for by considering the process as an adhesive joint formation at the front of the cylinder and the propagation of a crack (rupture) at the rear, a make–break adhesive joint process. The energy required for the "break" operation is substantially more than the energy gained in the "make" step with a net loss of energy. The action can be described as peeling. Roberts and Thomas[24] and Roberts and Jackson[25] have studied the surface energy and adhesion friction characteristics of rubber on smooth substrates and report values in agreement with this concept.

B. LABORATORY WEAR MEASUREMENTS

The work on laboratory wear or abrasion measurement may be divided into two areas: (1), empirical tests to simulate treadwear and predict compound performance; and (2), measurement conducted to elucidate wear or loss mechanisms.

Despite more than 50 years of effort to devise laboratory abraders that give a good prediction of the wear resistance in real-world situations, no abrasion device currently exists that does an acceptable job. As this review will show, this is not entirely the fault of the laboratory devices. The problem is mainly one of attempting to hit a moving target rather than a stationary one. There is no standardized method for measuring real-world tire wear because those who conduct outdoor treadwear tests cannot control or standardize the ambient conditions of the testing environment. Variation in the environment gives variation in results.

One of the main benefits of laboratory wear tests has been, and continues to be, their diagnostic capability. Depending on the conditions of their execution (type of abrasive, speed, load, and other severity factors), they can provide insight into wear mechanisms.

The texture of the abrading counter surface on a microscale, plays an important role in rubber abrasion. At the extremes this may be one of two types: (1), a surface with sharp asperities, or (2), a surface with substantially blunted or rounded asperities. The relevance of these two types of texture lies in the magnitude of the stress concentrations. If the stress concentrations are high, so that only a few asperities need pass over a given site to detach a particle, the important property is the rupture energy or tear resistance. In the opposite extreme, if a large number of asperity–rubber contacts are required to produce a wear particle with some incremental "surface damage" with each contact, there is a cumulative or fatigue damage aspect. Each pass over an asperity is equivalent to a minute increase in the growth of a fatigue crack, and resistance to this dominates behavior. Practical situations are a combination of these two extremes.

An important variant of the fatigue mechanism of wear is the case where chemically induced degradation of the rubber (properties) develops parallel to (or before) the repeated asperity stress cycle, each with its incremental increase in crack dimensions. This degradation

brings about a reduction in the critical rupture energy or in the required cumulative damage to produce a wear particle. Gent and Pulford[26] conducted laboratory abrasion tests with a blade abrader that was originally devised by Champ, Southern, and Thomas[27], Figure 13 schematically illustrates the form of the apparatus. Abrasion occurs due to the broad-front scraping action of the blade held vertical (on a radial line) to the surface of a revolving rubber wheel. Results from these tests are interpreted in terms of rubber fracture mechanics. An idealized schematic of the postulated action of the blade is shown in the figure.

The blade elongates a tongue of rubber in passing over the surface causing the "crack tip" at the base to grow until it ruptures, producing a wear particle. Champ, Southern, and Thomas[27] showed that the abrasion rate of gum (nonreinforced) rubbers was correlated with their fatigue-crack growth rates. Rubbers that crystalize upon stretching, like NR, were exceptions; the abrasion of NR is much greater than its crack-growth measurements would predict.

Blade abrasion normally produces abrasion patterns as depicted in Figure 14. Such patterns are also observed in abrasion by grinding wheels under some conditions where the asperities on the wheels are not excessively sharp. Abrasion patterns of this type may also be observed on tires under high severity conditions.

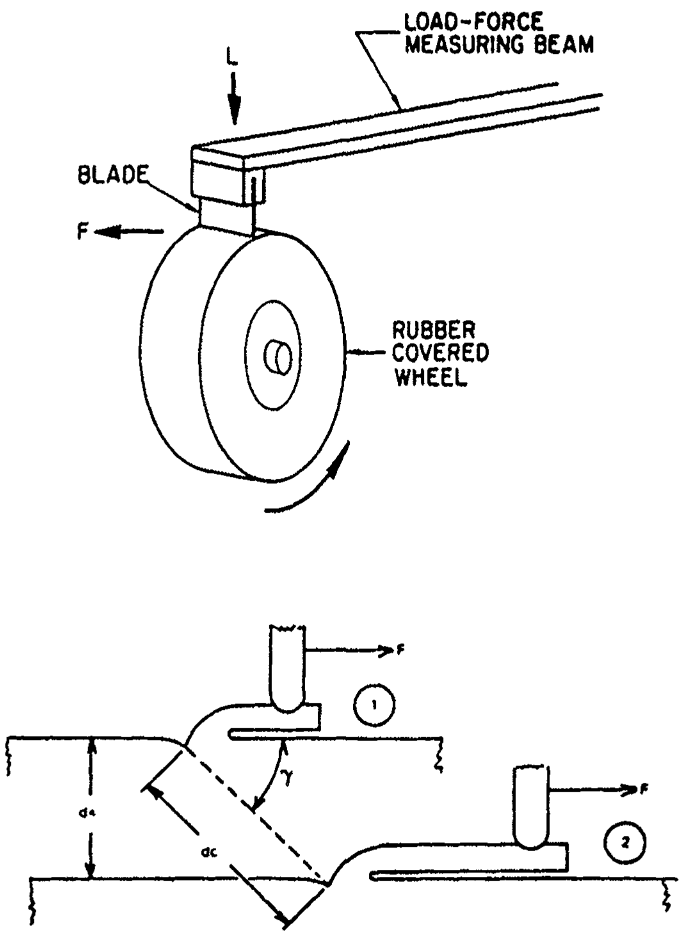

FIG. 13.—Blade abrasion and schematic blade action; stage 2 follows stage 1; tongue volume increases because of crack growth at base; from Gent *et al.*[26].

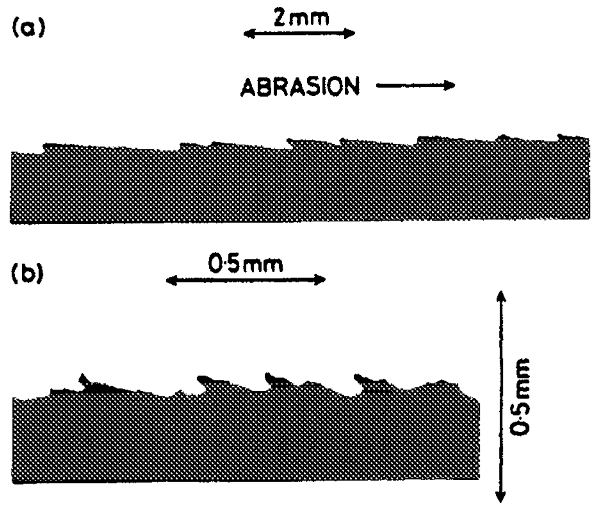

FIG. 14.—Abrasion pattern cross sections: (a) gum NR, (b) worn tread, from Schallamach[6].

One requirement for the development of an abrasion pattern is "unidirectional sliding." If random-direction-sliding conditions exist, such patterns ordinarily do not develop. The spacing between the ridges (the coarseness of the pattern) is a function of the rate of abrasion, the normal load, and the compliance of the rubber.

Gent and Pulford[26], using a blade device, show that rubber is abraded by two competitive mechanisms: (1), abrasion by fracture (tear, rupture) of the rubber; and (2), mechano-chemical degradation of a surface layer of the rubber, with the frequent loss of surface material in the form of a soft gum material or a dry powder, depending on the rubber.

The fracture type mechanism, (1), involves two concurrent somewhat different processes. There is a fine scale loss of rubber in the form of particles a few micrometres in diameter. Concurrent with this is a larger-scale loss of large particles several hundred micrometres in diameter, where material from the upper sides of the ridge patterns is torn loose. This loss occurs less frequently (on a time basis) than the small-scale highly repetitive process of small size particle removal, which takes place in the intervening areas between the ridge peaks.

The second main mechanism proposes the chemical breakdown of the polymer chains caused by high frictional forces on the surface layers. These intense frictional forces produce rapid chain elongation, and at isolated sites, sufficient energy is stored to cause individual chain rupture. When a chain is ruptured, two free-radical metastable ends are produced. The next step depends on the chemical nature of the rubber. For natural rubber (NR) and styrene–butadiene rubber (SBR), the next step is reaction with a free-radical acceptor, oxygen being the usual species. This stabilizes the radical, and a fully cleaved chain is the result. In this case, the cumulative effect of chain cleavage is a reduction in molecular weight, producing an oil-like substance. With rubbers like *cis*-polybutadiene (BR), free radical chain ends react with adjacent chains and crosslinking results. Crosslinking is the opposite of molecular-weight reduction, and the product is a dry, powdery abraded material.

Zhang[28] has recently reviewed the literature on rubber wear and includes work done up to 1989. In addition to the above topics, he reviews 3-body and wet abrasion mechanisms.

C. PAVEMENT CHARACTERIZATION

Prior to a discussion of abradability factors and treadwear, the character of the abrasion countersurface must be addressed. The principle method of characterizing pavement is by

means of road surface texture. Two scales of texture are recognized: macrotexture and microtexture. Macrotexture is defined by the size, distribution, and geometrical configuration of the individual aggregate particles and the voids surrounding such particles. A high-macrotexture pavement has large, usually angular, aggregate particles that stand proud from the underlying base and generate a large void volume between the particles.

The microtexture of a pavement is characterized by the degree of surface roughness of the individual aggregate particles. The scale of roughness is 10 μm or less. Pavements gradually change over a period of months or years, depending on traffic density, to a pseudo-equilibrium state of macro and microtexture. The macrotexture gradually increases because of the wearing away of the binder material, thus providing a greater void between aggregate particles. The microtexture decreases, mainly because of polishing of the aggregate particles. The prefix pseudo is used because seasonal cyclic variations in pavement friction properties, which are determined by microtexture, have been demonstrated in the U.K. by Williams *et al.*[29] and Bond *et al.*[30].

As shown in Figure 15, the seasonal change in wet skidding resistance by either test correlates with the seasonal change in the microtexture. During the summer months, the microtexture decreases because of intense traffic polishing, and during the winter it increases as a result of increased rain, frost, and other forms of weathering action. The pavement photomicrographs shown in Figure 15 are spaced throughout the Feb. to Feb. period. They clearly illustrate changes in microtexture of the order of 0.005 to 0.02 mm that occur as a result of the natural weathering action during the cold months and the polishing action of traffic dominant during the central warm summer period.

In the United States the same conclusions have been reached on the weathering of pavements. Kummer[31] attributed the increase in microtexture (in periods of increased rainfall) to a chemi–mechanical roughening. The effect is pronounced for limestone aggregates. He attributes increased microtexture development in low-temperature wet conditions as a result of an acidic attack from increased concentration of atmospheric carbon dioxide (CO_2) and other acidic pollutants dissolved in the water. The mechanical roughening component is due

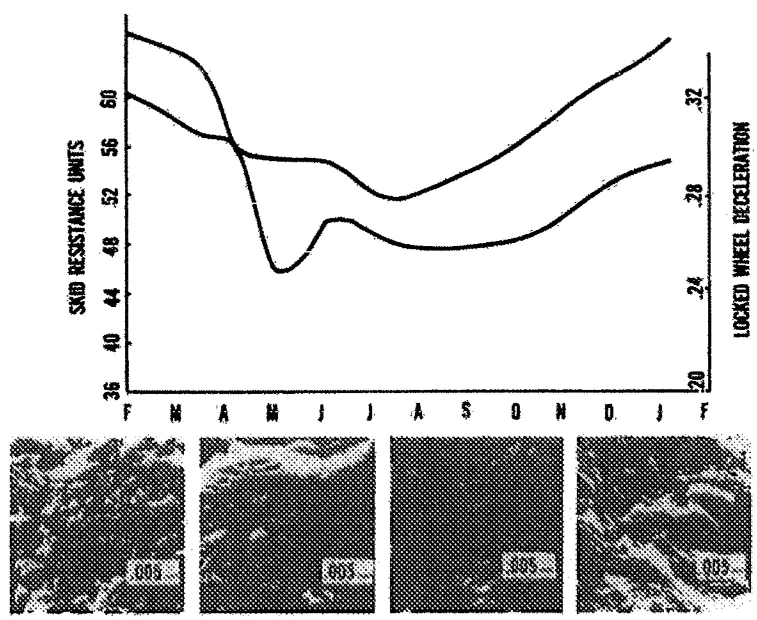

Fig. 15.—Skid resistance *vs.* month of year (Feb. to Feb.) and photomicrographs of sections taken from pavements monitored for skid resistance, from Bond, Lees, and Williams[30].

to a coarser particle size for the detritus or debris particles worn off the aggregate at low temperature (winter months). The tire acts as a lapping tool in this mechanical roughening.

Quite recently, Whitehurst and Neuhardt[32] have documented the changes in skid resistance of the reference skid test surfaces developed by the Federal Highway Administration for skid trailer calibration. Figure 16, taken from their publication, shows smoothed curves for the month-to-month variation of skid resistance for the years 1975 to 1983 on Primary Reference Surface 1 (PRS-1), located in Ohio. This is an aggregate surface with finely graded silica sand (no. 10–16 gradation) and an epoxy binder. Again, in agreement with the work done in the United Kingdom, high skid resistance is found during the winter months and low skid resistance during the summer months. Note the relatively constant seasonal variation for all the years tested.

D. TIRE WEAR *VS.* PAVEMENT TEXTURE

Other than occasional references in the trade literature to the fact that newly prepared pavements are abrasive and give high rates of treadwear, the scientific literature on treadwear *vs.* pavement texture is sparse. The main contribution is a paper by Lowne[33] in 1971. The treadwear of passenger tires was measured on a series of test pavements at the Transportation and Road Research Laboratory (and Proving Ground) in the U.K. Two types of tests were conducted: (1), very accelerated wear on a special test vehicle at 20° slip angle; and (2), tests on ordinary vehicles that were driven in a "figure 8" handling pattern with high cornering input.

Both sets of tests were in agreement, and they showed that the microtexture was a dominant factor in determining treadwear. Macrotexture played a minor role, with increased macrotexture giving slightly increased wear. Lowne showed that treadwear, W, was given by a multiple regression equation of the form

$$W = -9.2 + 90(S_{60}) + 18T, \tag{11}$$

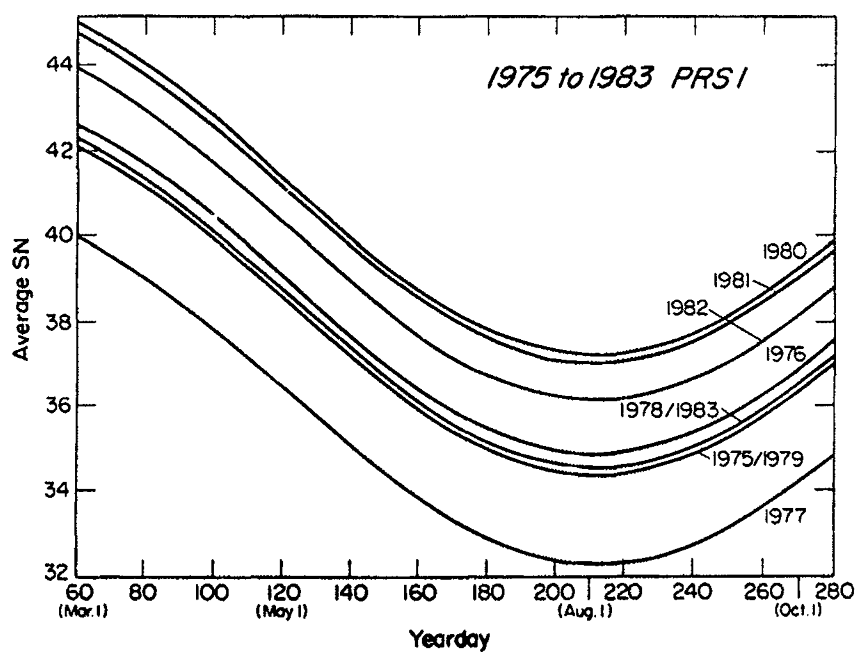

Fig. 16.—Seasonal variation in skid resistance of reference skid surface PRS-1 (Ohio) in years 1975 to 1983, from Whitehurst and Neuhardt[32].

where S_{50} is the wet cornering traction coefficient at 50 km/h for a smooth no-tread-pattern tire, and T is the macrotexture depth, normalized to a reference surface value of 1.

Parameter S_{50} is a measure of microtexture. The statistical importance of S_{50} and T is given by the confidence level values 0.95 and 0.75, indicating that S_{50} is substantially more important. Wet traction testing has shown that S_{50} is quite responsive to the microtexture of pavements. Thus we may conclude that the microtexture of a pavement, which must of necessity include the angularity (sharp edge) factor, is the controlling pavement characteristic in determining the influence of pavement texture on treadwear.

VI. ABRADABILITY—TREADWEAR PERFORMANCE

A. LOSS MECHANISMS

In this section we review actual treadwear performance and show how the four abradability-factor categories enumerated in Figure 2 (rubber, pavement, temperature, and contaminants) play a role in determining the relative contributions of the basic loss mechanisms (as outlined in Section V) to general treadwear performance.

We can summarize the loss-mechanism discussion of Section V for laboratory rubber abrasion by means of the diagram given in Figure 17. The diagram illustrates how the various loss mechanisms contribute to the value of the abradability term, A. The value of A is directly influenced, though the loss mechanism linkage, by the "factor values;" *i.e.*, what rubber is used, its T_g and degree of reinforcement?; what is the tire-pavement temperature?; is the road dry or wet?

The diagram shows two major mechanisms.

1. A condition, called "Frictional Regime," roughly equivalent to the concept of cohesive wear as described by Briscoe[15]. It is similar to what other investigators call fatigue wear, wherein crack propagation due to surface-shear forces produces wear particles. The response of the rubber in this mechanism is mainly *elastic;* large surface deformations on a microscale as indicated in Figure 18.

2. A condition given the title "Abrasive-Cutting Regime" which is equivalent to type 2 in the list of Section V, or abrasive wear, where a cutting action by sharp asperities removes

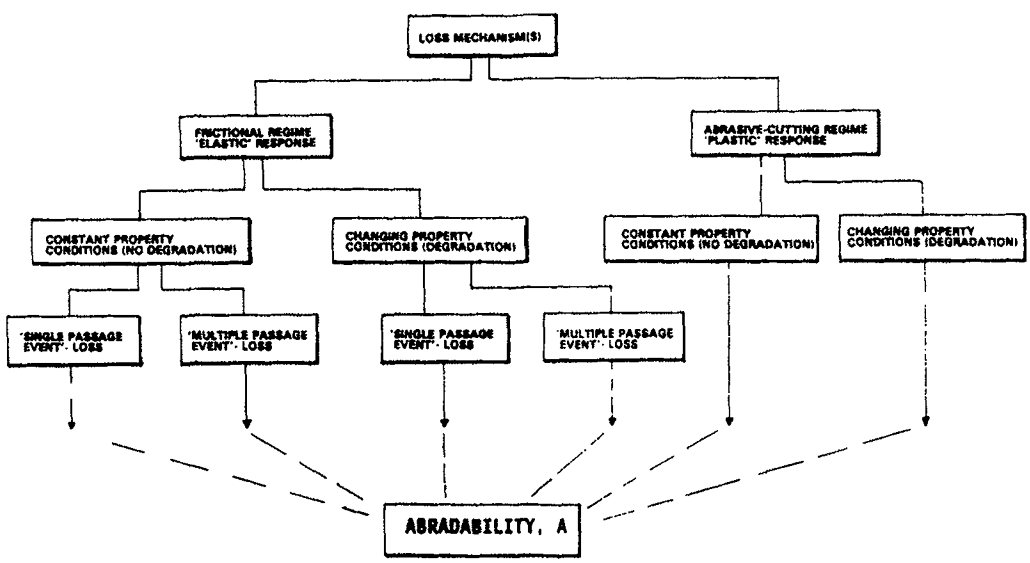

FIG. 17.—Block diagram—loss mechanisms for treadwear.

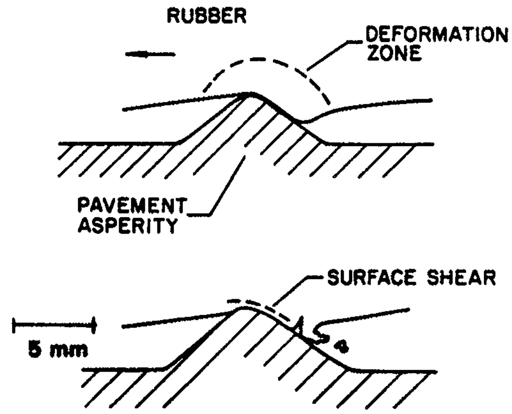

FIG. 18.—Frictional regime—"elastic" deformation response.

rubber particles. The rubber response in simple mechanical terms may be called "plastic." In more accurate terms, it is a viscoelastic response, with a high viscous component or a highly rate-dependent character. Figure 19 illustrates asperity–rubber contact for the Abrasive-Cutting Regime on a microscale. Note the 5 to 1 scale difference between Figures 18 and 19.

One of the characteristics of the Frictional Regime is the very frequent occurrence of numerous interactions of the rubber surface with asperities of the countersurface prior to any actual loss of wear particles. This type of action is called a multiple passage event loss in the blocks of Figure 17. The frictional energy intensity determines this type of behavior; if it is low to moderate, multiple passage event loss occurs. If frictional energy is high, loss may occur in a single passage event. The word "passage" in the context of Figure 17 refers to passage of a typical tread element through the footprint.

The first three A-factors (rubber, pavement, temperature) in Figure 2, cannot be reviewed in isolation; they strongly interact and must be discussed as a group. The fourth factor, pavement contaminants, is somewhat less interactive than the first three, and it will be reviewed as the discussion of the other three factors proceeds.

B. TREAD COMPOUND CHARACTERIZATION—T_g, REINFORCEMENT

A tread compound may be described by three major factors, each of which has subcomponents that directly influence wear. They are listed in Table VII. In the discussion to this point and in the diagram of Figure 17, the word "rubber" has been used in its broadest sense to mean the tread compound, the as-used composite material applied to the tire during

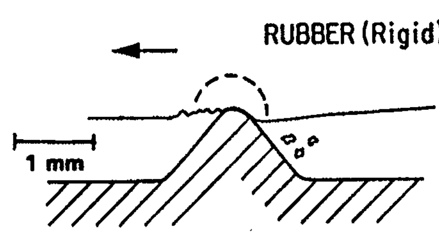

FIG. 19.—Abrasive-cutting regime—"plastic" deformation response.

TABLE VII

TREAD MATERIAL (COMPOUND) FACTORS

Factor	Characterized by
Rubber	glass-transition temperature
	factor "X"
Reinforcement system	carbon black:
	– concentration (content)
	– structure
	– surface area (inverse particle size)
	– surface chemistry
	process oil content
Cure and protective system	type of crosslinks
	– mono *vs.* polysulfide crosslinks
	pro *vs.* antioxidant byproducts of cure
	added antioxidants

its construction. In this section, we speak in a more detailed sense and use rubber in a specific context to mean the rubbery high polymer used in the basic formulation of the compound.

Rubbers used for tread compounds may be characterized mainly by their glass-transition temperature, T_g. The T_g parameter is adequate for tread performance characterization for a broad range of normally used rubbers, such as NR, SBR, and BR, but as the results discussed in a subsequent section will show, there is at least one other rubber factor, called "factor X."

The reinforcement system may be characterized as shown. Process oil, a required adjunct to the carbon black needed to control processing operations, is considered part of the reinforcement system. However, only carbon-black factors will be discussed in detail.

Cure-protective system factors may be characterized according to: (1), whether the crosslinking is produced by a system that generates nonsulfur or sulfur-containing crosslinks; (2), for the sulfur regime, the predominance of mono or polysulfidic crosslinks; (3), the type of potential by-products from the cure reactions—these may be pro- or anti-oxidative in nature; and (4), the type and amount of added antioxidants in the compounding operation.

The influence of the glass-transition temperature on treadwear has been recognized for some time. Kienle *et al.*[34] conducted a comprehensive test program on this topic. Treadwear tests were conducted in both summer and winter months, and Kienle found a correlation between rate of wear and T_g. He reported on the variation between summer and winter tests by calculating wear-rate temperature coefficients based on the two seasonal rates. Low T_g compounds had positive coefficients; high T_g compounds had negative coefficients. Although Kienle alluded to possible pavement-condition seasonal changes, this was not an important feature of his work.

The combined effect of T_g, degree of reinforcement, and environmental conditions on treadwear has been demonstrated by Veith[35] in treadwear tests conducted on a seasonal basis. Two series of tread compounds were prepared and tested *via* a multitread section technique by way of convoy and accelerated trailer testing. The compounds consisted of various blend ratios of NR, SBR, and BR rubbers with two levels of carbon-black reinforcement; 80/50 or 72/40 (black/oil) as the high level and 45/5 as the low level. See Tables VIII and IX for more details.

Treadwear tests were conducted simultaneously on five different test routes during three seasonal periods: January, March and July. The mean daily ambient temperatures for these periods were 5, 16, and 29°C respectively. The five courses were located in sufficient proximity to each other in southwest Texas so that the above average temperatures were applicable to each course. Figures 20 to 24 show the rate of wear plotted *vs.* weighted average T_g for

TABLE VIII

COMPOUND FORMULATIONS FOR SERIES 1 AND 2

Compound	SBR	BR	NR	Black/oil[c]	avg. T_g, °K	Durometer
(Series 1)[a]						
1	60	40	—	80/50	198	65
2	80	20	—	80/50	208	64
3	100	—	—	80/50	217	66
4	50	50	—	72/40	194	64
5	75	25	—	72/40	205	63
6	100	—	—	72/40	217	65
7	—	50	50	45/5	185	61
8	—	—	100	45/5	200	63
9	—	25	75	45/5	193	62
10[b]	—	—	100	45/5	200	69
(Series 2)						
1	—	75	25	60/25	178	62
2	—	35	65	60/25	190	62
3	18	82	—	60/25	178	65
4	25	—	75 (CIIR)[d]	65/25	207	76
5	100	—	—	65/35	217	65
6	100	—	—	75/40	217	65
7	65	35	—	65/32	201	66
8	65	35	—	75/37	201	66
9	25	—	75 (NBR)	65/35	219	68

[a] Compounds 1–9 cured with conventional Santocure MOR + sulfur system.

[b] Compound 10 cured with DPG + high sulfur (4 phr) system.

[c] N234 carbon black used with aromatic oil in Series 1; N339 carbon black used with aromatic oil in Series 2.

[d] CIIR = chlorinated butyl rubber; conventional cure systems used for all compounds in Series 2.

the three periods (January, March, July) for all five test courses. Discussion of the wear-rate behavior of the DPG cure, Series 1, Compound 10, will be postponed until later. The use of a weighted average T_g for rubber blends is justified on the basis that, no matter what the phase morphology of the blends (the size of the phase domains of the two rubbers), the individual domain particles viscoelastically respond based on their own T_g. The overall response is assumed to be linear with blend composition and weighted-average T_g.

The two separate Series 1 blend systems, SBR/BR and NR/BR, are discussed separately. As BR is blended into either SBR or NR, the weighted average T_g shifts to lower values. Important features of these plots are enumerated as follows: (a) For the SBR/BR system, a good direct linear relationship is found between rate of wear, R_w, and T_g for all test routes. (b) The slope of this R_w *vs.* T_g relationship decreases in moving from the cool (5°C) test to the hot (29°C) tests. (c) The most pronounced R_w *vs.* T_g relationship (steepest slope) is found for the Fort Davis-Mountain test route. (d) For the NR/BR system, a less well-defined R_w *vs.* T_g relationship is apparent, although the three points generally give a fairly good linear fit. (e) The slope of the NR/BR *vs.* T_g relationship shifts from positive for the cool tests (5°C), to negative for the hot tests (29°C). As the positive-to-negative shift occurs, all points are shifted upward relative to the line established by the SBR/BR system. This shift is minimal for the lowest-wear route, I10/I20.

The reason that the rate of wear *vs.* T_g correlation (regression) lines are different for the two-blend systems is the difference in degree of reinforcement in the two systems: 45 phr *vs.* 72–80 phr black, respectively. This is documented with supplemental information and analysis in Section VI D. In the discussion to follow, the influence of any potential effects of changes in pavement microtexture, winter *vs.* summer, are determined in an indirect manner,

TABLE IX

DETAILS ON SERIES 1 AND 2 TREADWEAR TESTING

Series 1

Test: Regular convoy vehicles on multisection radial tires; total distance of 12 000 km.

Conditions: RWD vehicles; 80% T&R load, 180 kPa inflation pressure, rotated around all four wheel positions, average depth loss measured.

Test routes: No. 1 = UTQG course in San Angelo, TX.

No. 2 = Automotive Proving Grounds (APG), Pecos, TX with 7 to 1 (distance) lap ratio for two courses; (1), circular track with low cornering input; and (2), high-cornering curved roadway course.

No. 3 = APG 3/1 lap ratio.

No. 4 = interstate (I10/I20) highway.

No. 5 = secondary roads through Ft. Davis mountains.

Series 2

Test: Accelerated cornering trailer; same loads and inflation pressure as above; programmed ±angles of 1 deg for slip and camber, average depth loss for typical multisection radial tires.

Test route: Ohio interstate highway.

Conditions for tests:

	Test No. 1	Test No. 2
Time period	June–July	November
Pavement	dry	wet
Temperature, °C		
air	31	7
pavement	39	7
tire (surface)	61	21
Cornering coefficient[a], g	0.199	0.201

[a] g = tire cornering (lateral) force/tire load.

since it was not possible to make any direct microtexture measurements over the 400 mile test courses.

The test results may be interpreted by defining an *apparent* temperature coefficient, α_A, as follows with $R_w(1)$ and $R_w(2)$ equal to the mean wear rate for any two periods 1 and 2:

$$\alpha_A = \left\{\frac{R_w(2) - R_w(1)}{(T_2 - T_1)}\right\} \cdot \left\{\frac{1}{\bar{R}_w}\right\} \cdot 100, \tag{12}$$

where T_1 = temperature period 1, T_2 = temperature period 2, and $\bar{R}_w$ = the mean R_w over both periods. The apparent wear-rate temperature coefficient, α_A, is given in % per °C units; and, since any changes in microtexture will influence R_w (at either T_2 or T_1), the value of α_A is influenced by microtexture level. Table X lists the α_A coefficients. For series 1, we find both positive and negative α_A values that range from a low (negative) of −1.65% °C^{-1} to a high of 3.2% °C^{-1}.

Figure 25 shows plots of α_A *vs.* T_g for two of the test courses. Good linear negative slope dependence of α_A on T_g is obtained, again with separate correlation lines for the two blend-reinforcement systems. Note that α_A grows more negative as T_g increases. For the SBR/BR

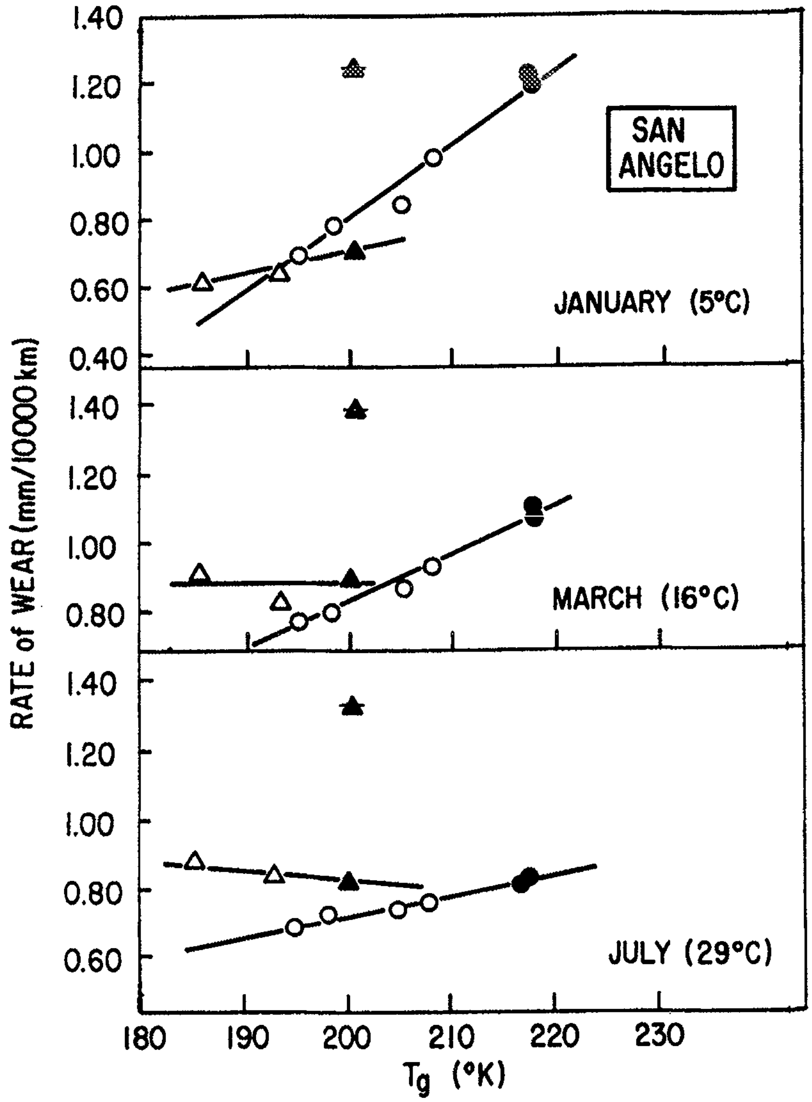

FIG. 20.—Rate of wear at San Angelo *vs.* glass-transition temperature (deg K); △ = NR/SBR, ▲ = 100% NR, ○ = SBR/BR, ● = 100% SBR, -▲- = NR-DPG cure.

system at the San Angelo test site, essentially all α_A values are negative; the higher the T_g the more negative is α_A. The NR/BR low-reinforcement system has the same slope trend as SBR/BR, but all α_A values are positive.

The slope behavior of the data at test site APG 7/1 is similar to San Angelo, but now all α_A values are positive; all the points are displaced upward, and again there is a difference in location of the regression lines for NR/BR *vs.* SBR/BR systems. At equal T_g, the α_A values are higher for the NR/BR system, which shows more apparent temperature sensitivity compared to the SBR/BR system. The other plots are similar to one of these two basic types; APG 3/1 and I10/I20 are similar to APG 7/1—all α_A values positive; and the Ft. Davis route is like San Angelo—essentially all α_A values are negative.

Further analysis of these data is presented in Figure 26 where attention is restricted to the SBR/BR system, all α_A *vs.* T_g correlation lines are consolidated, and the points are removed

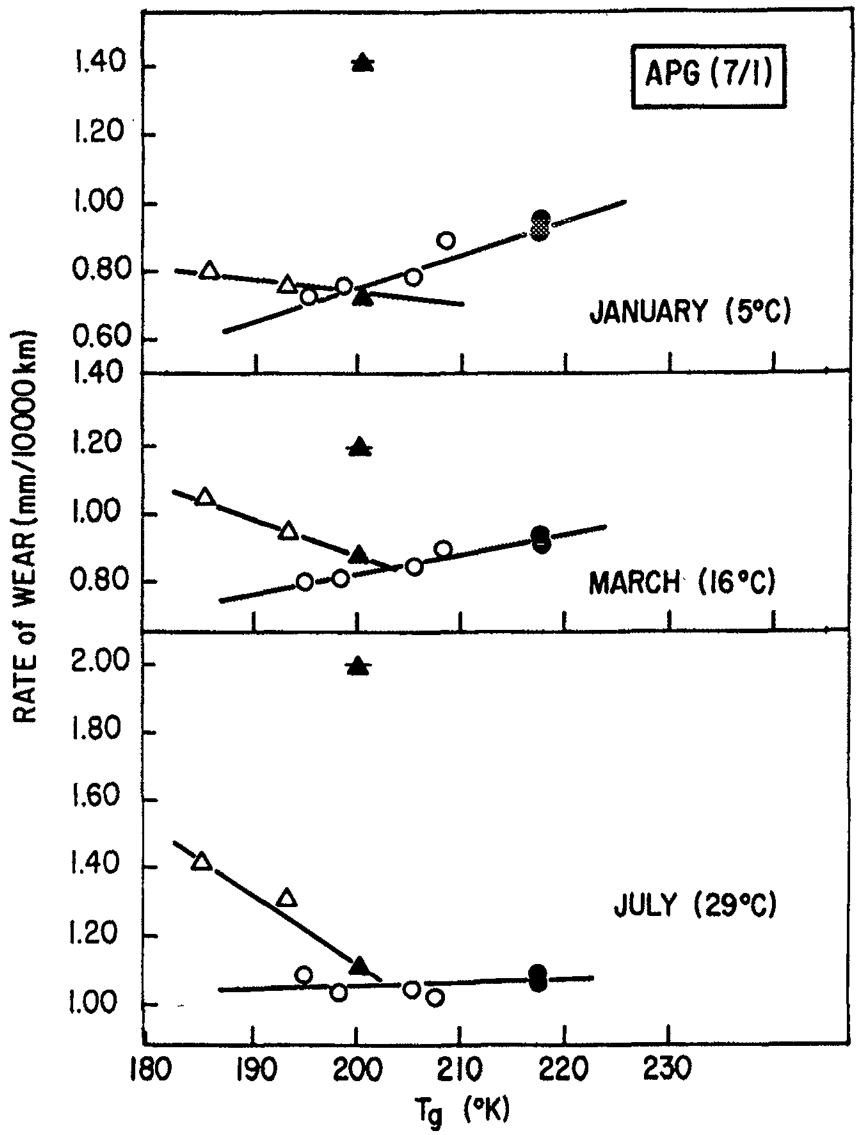

FIG. 21.—Rate of wear at APG (7/1) *vs.* glass-transition temperature (deg K); △ = NR/SBR, ▲ = 100% NR, ○ = SBR/BR, ● = 100% SBR, -▲- = NR–DPG cure.

to avoid confusion. There are two groupings of the regression lines: APG 7/1, APG 3/1, and I10/I20 form an upper group in which all α_A values are positive; San Angelo and Fort Davis form a lower group with essentially all α_A values negative. In the interpretation to follow, a strong reliance is placed on the fact that, for typical SBR, NR, and BR rubbers or blends, the true temperature coefficient of wear is always a positive value. The evidence for this will be reviewed in a subsequent section on direct temperature effects on abradability. The validity of a true positive α is assumed for the next development.

If the increase in pavement microtexture (mTx) is large in the summer to winter transition, it will out-balance a true positive temperature coefficient for all compounds and produce a net negative α_A. If the change in mTx is small, the true positive temperature coefficient out-

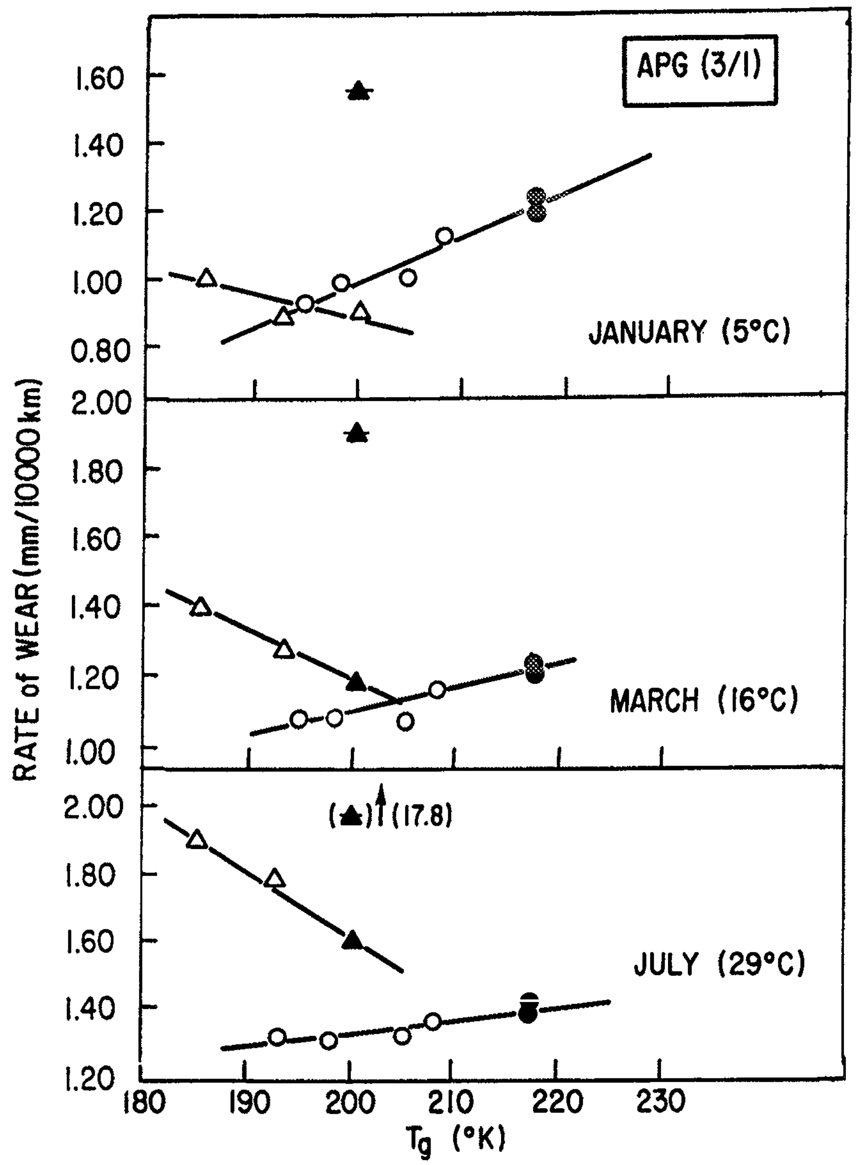

FIG. 22.—Rate of wear at APG (3/1) *vs.* glass-transition temperature (deg K); △ = NR/SBR, ▲ = 100% NR, ○ = SBR/BR, ● = 100% SBR, -▲- = NR–DPG cure.

balances this with a net positive α_A. Thus, the five test routes can be placed in two groups according to what happens to their microtexture level, summer *vs.* winter.

Weathering-resistant (small change in mTx)

Test routes: APG 7/1; APG 3/1; and I10/I20.

Weathering-prone (large change in mTx)

Test routes: San Angelo and Fort Davis-Mountain.

C. INTERPRETATION OF RESULTS: T_g, REINFORCEMENT AND SEASONAL VARIATION

All of the following aspects have to be brought into a common framework to better explain the results: the complex dependence (positive, zero, and negative slope) of R_w on

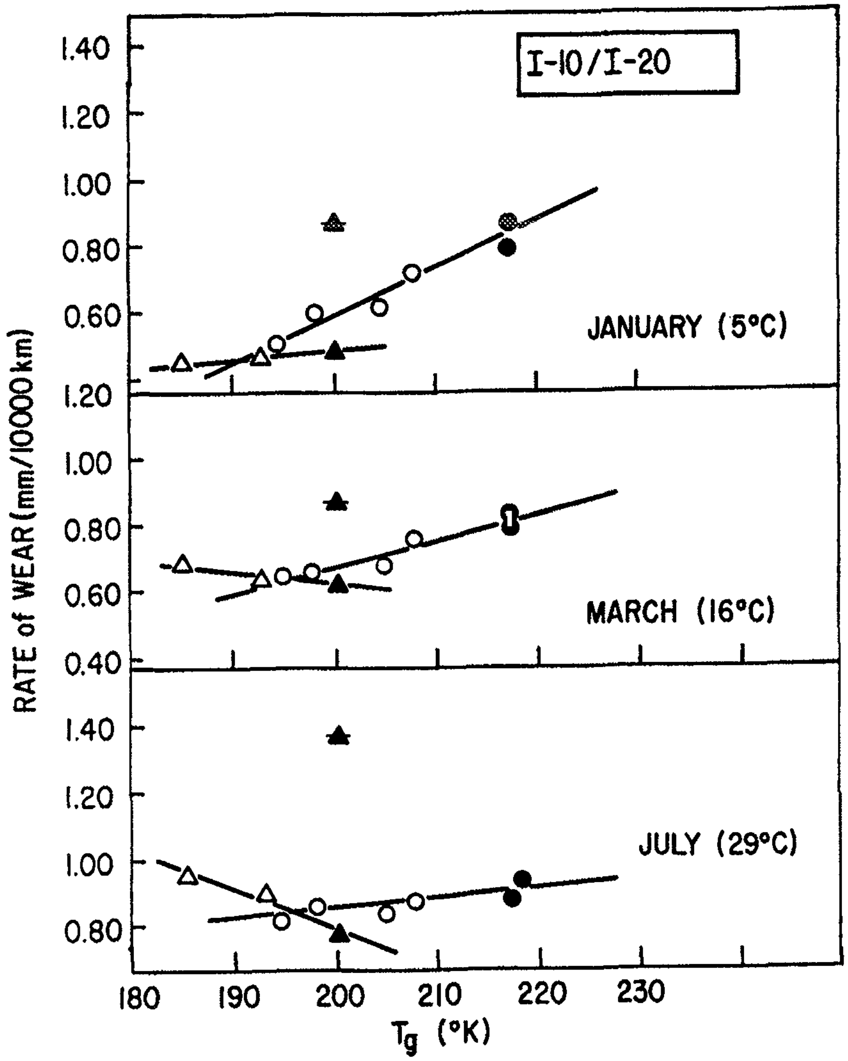

FIG. 23.—Rate of wear Interstate Highway I10/I20 *vs.* glass-transition temperature (deg K); △ = NR/SBR, ▲ = 100% NR, ○ = SBR/BR, ● = 100% SBR, -▲- = NR-DPG cure.

T_g; the variation of R_w *vs.* T_g dependence upon reinforcement level; the inverse dependence of α_A on T_g and reinforcement level.

Two sources furnish material for interpretation. Figure 27 illustrates how both of the important external factors, ambient temperature and pavement microtexture, vary on a seasonal basis; the sine-wave nature of both of these is clearly seen. (The solid and broken line is the average Whitehurst–Neuhardt skid resistance curve from Figure 16.) Skid resistance measures pavement microtexture. The temperature curve represents monthly mean (daily average) temperatures recorded at the Automotive Proving Grounds, Pecos, Texas, during 1983 and 1984. The important feature of Figure 27 is that the two curves are out of phase. Maximum microtexture occurs at minimum ambient temperature and *vice versa*. The second source for interpretation is the extensive literature on polymer abrasion as reviewed in Section V. Also Lancaster[36] has reviewed the wear of polymers. From his own work and

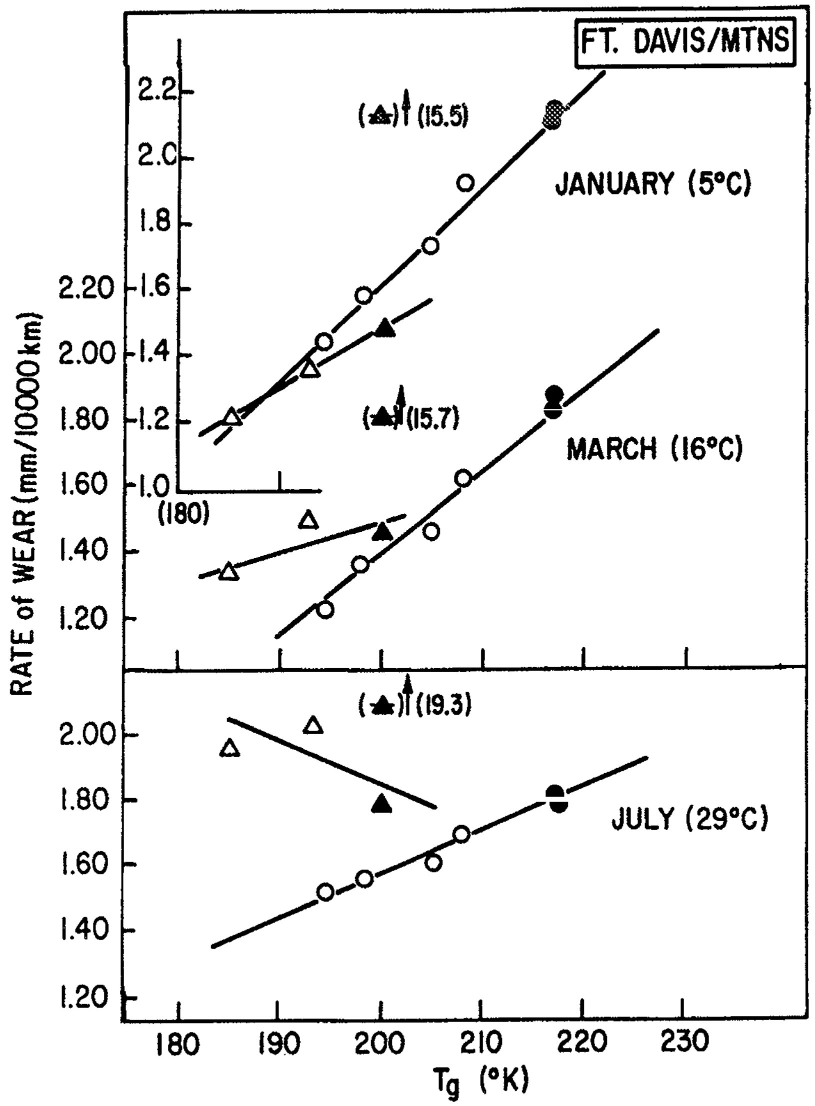

FIG. 24.—Rate of wear Ft. Davis Mountain route *vs.* glass-transition temperature (deg K); △ = NR/SBR, ▲ = 100% NR, ○ = SBR/BR, ● = 100% SBR, -▲- = NR-DPG cure.

the combined work of numerous previous investigators, he clearly shows that polymer wear consists of two main types as defined in Section VI A on loss mechanisms.

Wear Mechanism 1: Wear is produced during an elastic (viscoelastic) deformation response and loss is due to a tear-tensile rupture failure. Abrasion resistance is attributed to tear-tensile rupture strength and reinforcement by fillers (carbon black). The deformation zone is relatively large compared to the asperity tip, and interface pressures are nominal due to the large true contact area.

Wear Mechanism 2: Wear is produced during a plastic deformation response by a cutting-abrasive action, frequently with abrasion marks parallel to the line of relative surface motion. Abrasion resistance is attributed to low modulus and the ability to resist rupture failure in a small point contact deformation zone with high interface pressures (compared to Mechanism 1) because the true contact area is smaller.

TABLE X

APPARENT TEMPERATURE COEFFICIENT OF WEAR, α_A, % PER °C

		α_A, for each indicated test route						
Series 1								
Compound	Features[a]	SA	APG 7/1	APG 3/1	I10/I20	Ft. Davis	Interstate highway	T_g °K
1	SBR/BR 60/40/80	−0.23	1.30	1.13	1.49	0.04		198
2	SBR/BR 80/20/80	−1.05	0.53	0.81	0.87	−0.51		208
3	SBR 100/80	−1.62	0.57	0.51	0.40	−0.71		217
4	SBR/BR 50/50/72	0.08	1.78	1.45	2.27	0.31		194
5	SBR/BR 75/25/72	−0.62	1.14	1.08	1.41	−0.22		205
6	SBR 100/72	−1.65	0.58	0.68	0.50	−0.71		217
7	NR/BR 50/50/45	1.55	2.54	2.62	3.22	2.05		185
8	NR 100/45	0.65	1.90	2.37	2.15	0.85		200
9	NR/BR 75/25/45	1.26	2.34	2.77	3.01	1.69		193
10	NR 100/45	0.35	1.45	1.62	2.01	0.89		200
Series 2								
1	NR/BR 25/75/60						3.52	178
2	NR/BR 65/35/60						2.64	190
3	SBR/BR 18/82/60						3.39	178
4	SBR/IIR 25/75/65						−2.00	207
5	SBR 100/65						1.51	217
6	SBR 100/75						0.73	217
7	SBR/BR 65/35/65						2.31	201
8	SBR/BR 65/35/75						1.25	201
9	SBR/NBR 25/75/65						−0.22	219

[a] Explanation of Features Notation: example for SBR/BR 60/40/80; SBR/BR = rubbers in blend; 60 = phr SBR, 40 = phr BR, 80 = phr black.

A high degree of reinforcement is not necessarily good, since modulus is increased along with an increase in strength. This increase may out-balance the increased reinforcement strength for a net increase in abrasion. A high microtexture countersurface (many point contacts) increases the tendency to Mechanism 2 wear.

In the discussion and diagrams to follow, Mechanism 1, elastic deformation wear, is called "E-Wear"; Mechanism 2, plastic deformation wear, is called "P-Wear". Mechanism 1 is the Frictional Regime as given in Figure 17; Mechanism 2 is the Abrasive-Cutting Regime.

The next step in this development is to demonstrate general relationships for the influence of microtexture, temperature, and reinforcement level for the Series 1 SBR/BR system. As previously described, we have two groups of test sites: First, the San Angelo and the Fort Davis-Mountain route, which are prone to experience a sharp increase in mTx, summer to winter. We call these two the high-mTx sites. The APG and I10/I20 test sites were shown to be much less prone to a weathering process that increased the mTx. They therefore are low-mTx sites.

We select 5°C (winter) as the low temperature, and 29°C (summer) as the high test temperature. At each of these temperatures, the actual curves generated in the plots of Figures 20 to 24 are used to produce an average curve, R_w *vs.* T_g, for low and high mTx at two different temperatures, 5°C (low) and 29°C (high). This is done separately for Table VIII Compounds 1–6 the high reinforcement level (SBR/BR), and Compounds 7–9, the low reinforcement level (NR/BR). Figures 28 and 29 illustrate the results of the averaging process for the curves of wear rate *vs.* T_g.

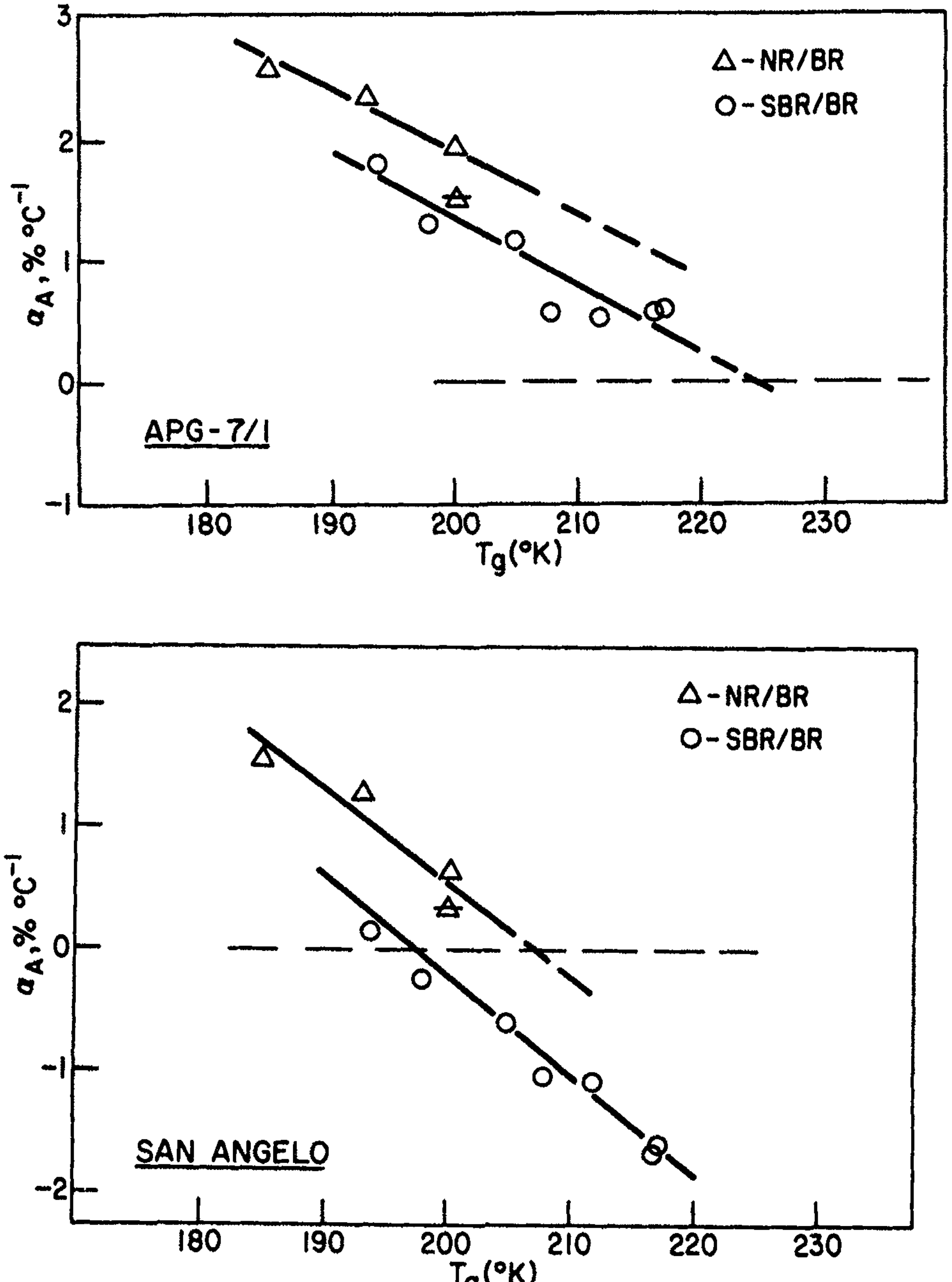

FIG. 25.—"Apparent" temperature wear rate coefficient, α_A *vs.* glass-transition temperature (deg K) for two typical test routes; top, APG 7/1; bottom, San Angelo.

The pure mechanisms, E-wear and P-wear, must be considered in a realistic sense. Only under controlled and selective laboratory conditions would it be possible to achieve 100% E-wear without some P-wear and, conversely, achieve all P-wear without some E-wear. Therefore, in any real-world treadwear situation, there will be both E-wear and P-wear. Based on the foregoing discussion:

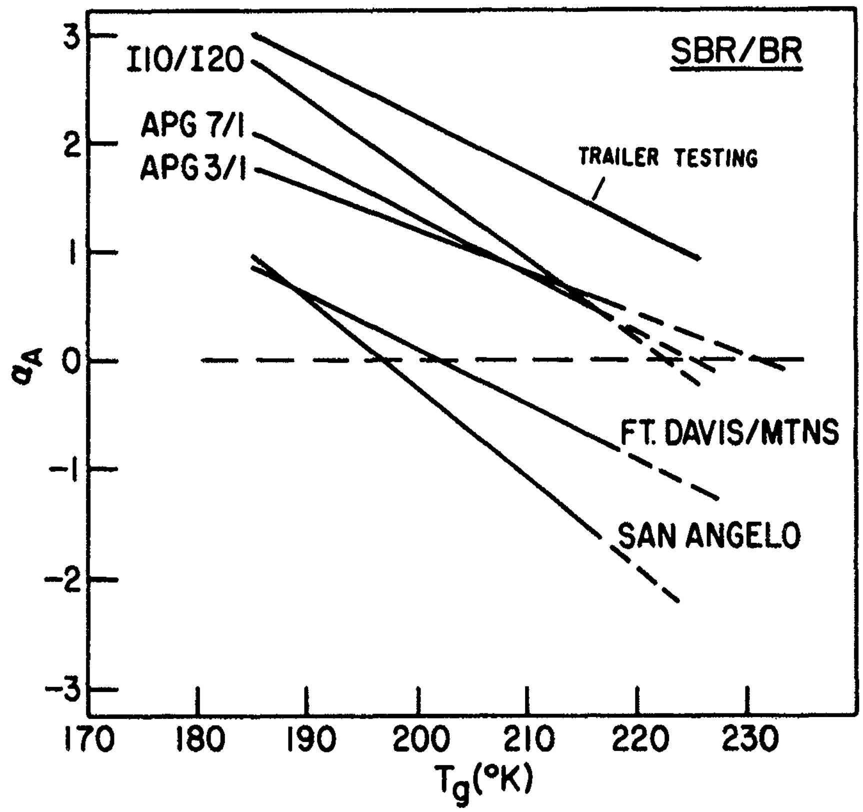

FIG. 26.—"Apparent" temperature wear rate coefficient α_A *vs.* glass-transition temperature (deg K) for all five test routes for SBR/BR blend system; trailer curve discussed in Section VI D.

E-wear is favored by:
(1) Low pavement mTx;
(2) High interface temperatures, especially in combination with (3) and (4).
(3) Low-T_g rubbers;
(4) Soft, poorly reinforced compounds.
P-wear is favored by:
(1) High pavement mTx;
(2) Low interface temperatures, especially in combination with (3) and (4).
(3) High-T_g rubbers;
(4) Hard compounds (high black level).

A point will exist along the T_g axis of R_w *vs.* T_g, where the rate of E-wear equals the rate of P-wear. To the left of this point, E-wear will dominate behavior; to the right, P-wear will dominate behavior. This point is illustrated in Figures 28 and 29 by a vertical broken line; it is placed on the plots solely on the basis of an educated guess.

Hardness, rigidity, or dynamic response must be understood in relation to the frequency or rate of stress (strain) application as tread elements slide over surface asperities. This frequency varies in a range of 0.1–10 kHz. As the frequency of strain application increases, (dynamic) modulus increases. Thus, at certain levels of temperature and frequency,. the effective (dynamic) modulus of rubber can be quite high.

With the foregoing discussion as background, the curves in Figures 28 and 29 may be interpreted as follows:

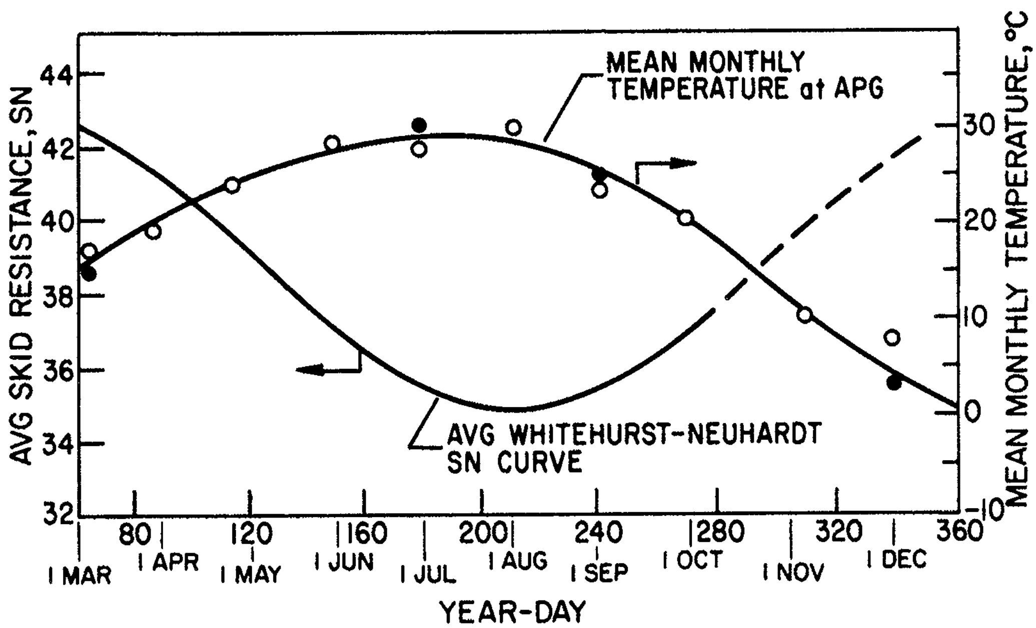

FIG. 27.—Seasonal variation in ambient temperature and pavement microtexture (skid resistance); ○ = 1983, ● = 1984.

Plot 1.—P-wear dominates treadwear performance over most of the T_g range; the interface temperature is low and the modulus and reinforcement level are high. The higher the T_g, the greater is the wear. High mTx promotes a much faster increase in wear with T_g compared to low mTx, which is less favorable to P-wear. Thus, at high T_g there is a greater difference in R_w (high mTx–low mTx) than at low T_g, where the E-wear mechanism is strongest.

Plot 2.—Interface temperature is now high, the tread compounds are softer and R_w is in general lower for the high-mTx curve due to reduced P-wear. The low-microtexture R_w is higher for the low end of the T_g range, compared to Plot 1, because low-T_g rubbers are more temperature-sensitive (high α) and the increased temperature has preferentially increased the wear in this low-T_g region.

Plot 3.—The R_w *vs.* T_g curve for high mTx is lower in slope than its counterpart in Plot 1, because of the lower modulus for the low-reinforcement series; lower modulus at low temperatures means lower P-wear. The low-mTx curve now actually has a negative slope; R_w slightly decreases with increased T_g. Rupture (tear-tensile) strength is slightly increasing with T_g, hence lower wear (P-wear). The general level of wear is low, due to low microtexture and temperature.

An extreme difference exists between high- and low-mTx wear at high T_g, due principally to the enhanced R_w resistance for low mTx. The dashed line is the low mTx–high reinforcement line of Plot 1. It illustrates the influence of the higher modulus for the high-reinforcement series. The difference between the two is greatest at high T_g. Both high T_g and high black levels (at these temperatures) produce dynamically rigid tread compounds that poorly resist P-wear.

Plot 4.—An enhanced negative slope exists for both levels of mTx. The low-T_g end of both curves of Plot 3 have been shifted upward in Plot 4, again because low-T_g rubbers are very temperature sensitive. High mTx has a nominally higher R_w level almost parallel to the low mTx curve. Again, the negative slopes are a combination of two factors: low-T_g rubber wear temperature sensitivity and a mild increase in tear-tensile rupture strength as T_g increases.

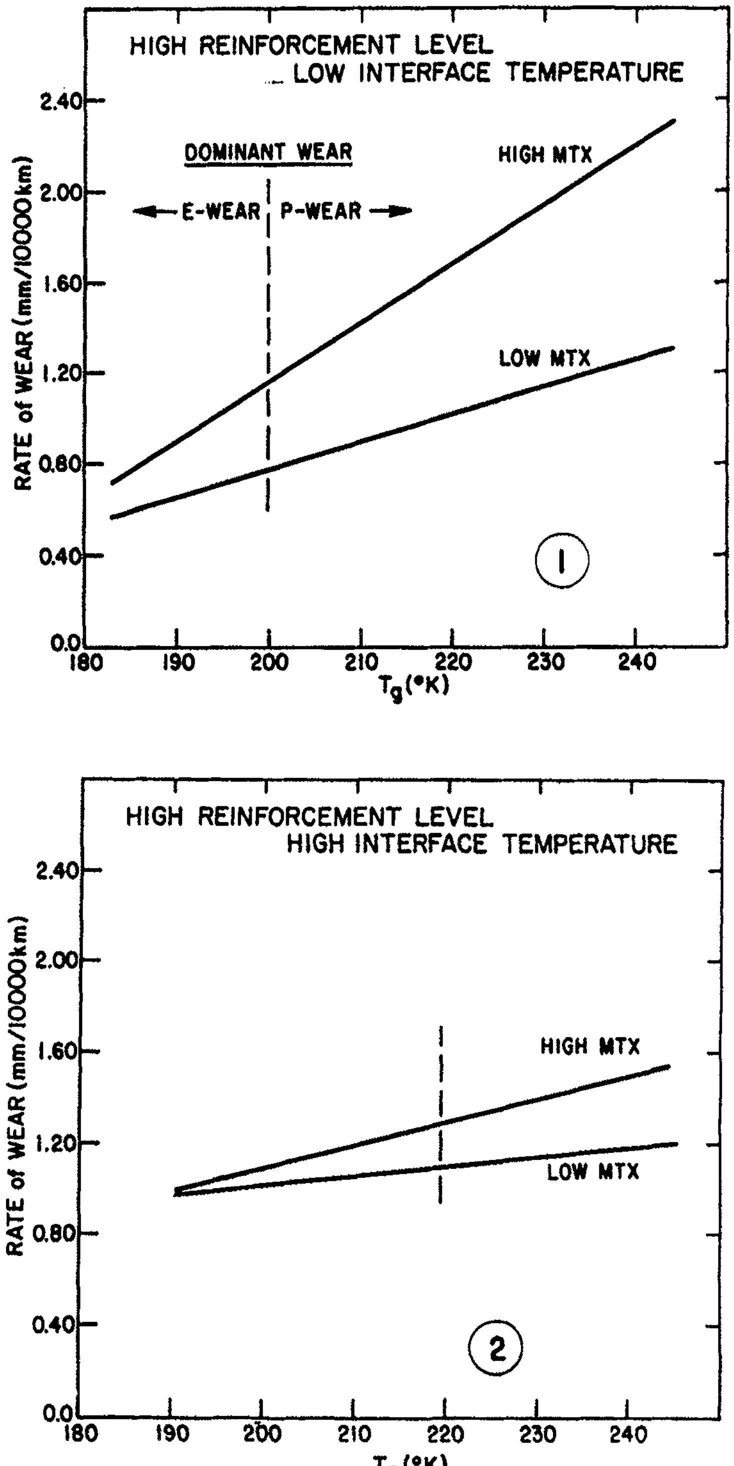

FIG. 28.—"Average" wear rate *vs.* glass-transition temperature (deg K) for high reinforcement level; for low- and high-temperature conditions and for low and high pavement microtexture.

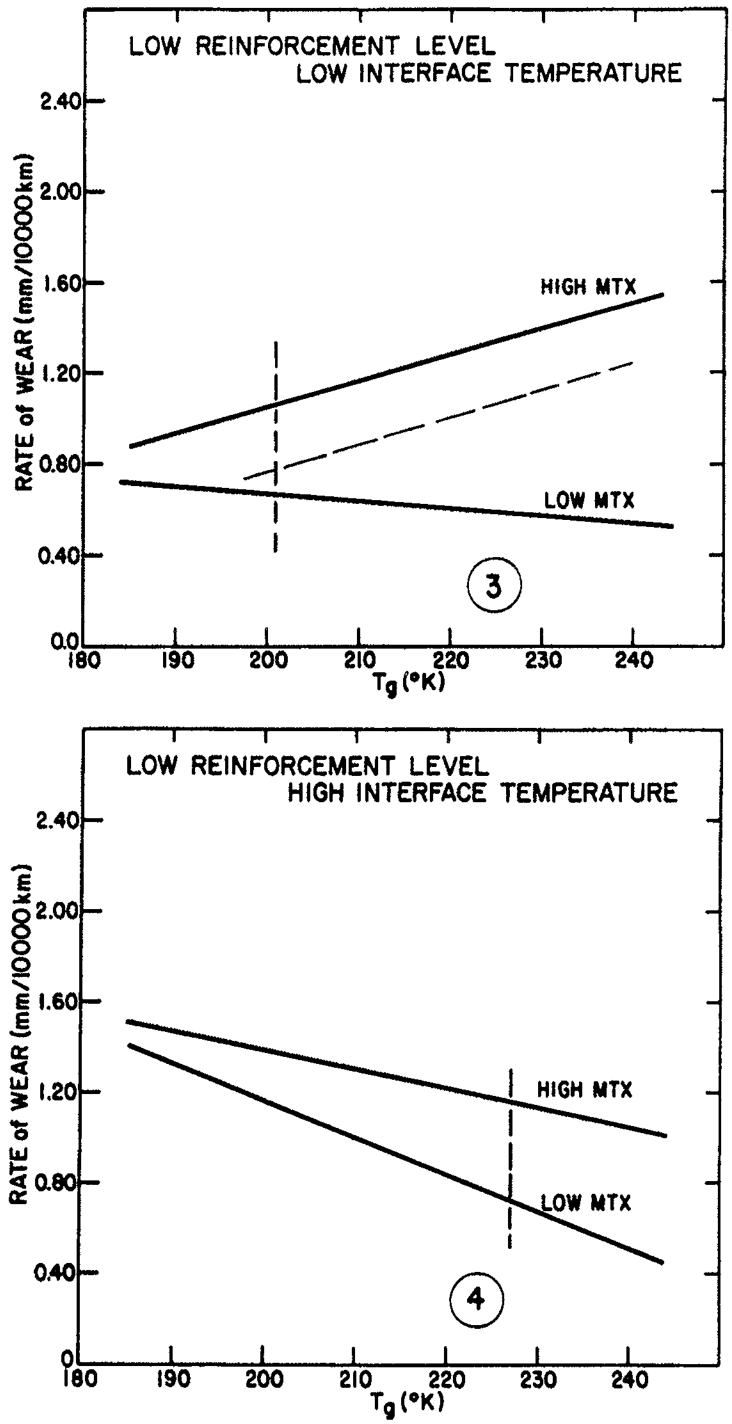

FIG. 29.—"Average" wear rate *vs.* glass-transition temperature (deg K) for low reinforcement level; for low- and high-temperature conditions and for low and high pavement microtexture.

D. APPARENT TEMPERATURE COEFFICIENTS—TRAILER TESTS

The wear rates for the cool, wet *vs.* the hot, dry testing conditions outlined in Table IX were used to calculate apparent temperature coefficients, of wear, α_A. These Series 1 and 2 coefficients are given in Table X. Figure 30 illustrates the relationship between Series 2 trailer test α_A values and T_g. The general α_A magnitude and the appearance of the curves are identical to those found for the convoy testing; see Figure 26, for SBR/BR trailer *vs.* convoy curves. There are two important pieces of evidence in Figure 30 that support the general concept developed in Section VI C; *i.e.*, the vertical position of the NR/BR curve in the α_A *vs.* T_g plots is due to the lower level of reinforcement (less carbon black) in the NR/BR blends and not due to some inherent effect attributed to the presence of NR.

First, the position of the curve for 60–65 phr black (less reinforcement) is higher than the 75 phr curve (more reinforcement). This is the same relationship as found when comparing the 45 phr black NR/BR blends with the 72–80 phr black SBR/BR blends of Series 1.

Second, the points that establish the 60–65 phr line are for two different rubber blends, SBR/BR and NR/BR; both sets of points fall on the same line. There is thus no direct influence of NR *per se* on the vertical position of the α_A *vs.* T_g curves; this position is solely due to black level or degree of reinforcement.

An additional literature citation is necessary for proper background on the development of this two-mechanism interpretation. In 1967, Bulgin and Walters[37] published on the abrasion of rubber encompassing tires, shoe soles, belting, etc. They recognized the two main mechanisms, E-wear and P-wear, and showed that these two types of wear were promoted by

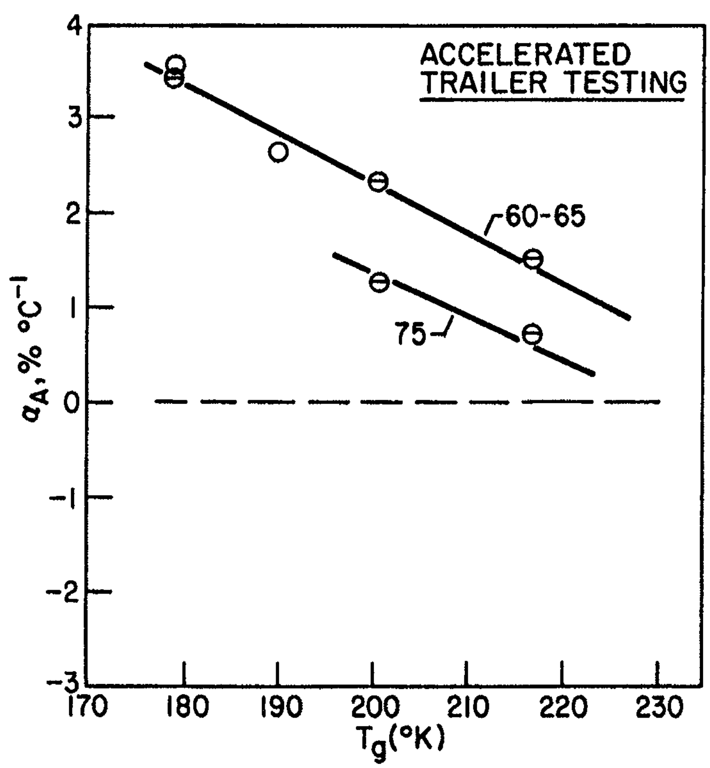

FIG. 30.—Compound Series 2 trailer tests, apparent wear-rate temperature coefficient α_A *vs.* glass-transition temperature (deg K); O = NR/BR, ⊖ = SBR/BR; 60–65 and 75 = phr carbon black in compounds for indicated blends.

different surface texture. They specifically implied that tire wear was a combination of E-wear and P-wear, although they did not use these terms. They also recognized the seasonal basis of the changing road-surface conditions, although their work was done prior to the work by Lowne[33]. Thus, the Bulgin and Walters work provides a firm foundation for this analysis.

E. FACTOR "X"

For NR, SBR, BR, and the more modern variants of SBR, the solution-polymerized styrene-butadiene polymers, T_g is the primary rubber characterizing parameter for treadwear performance. If, however, a broader range of rubbers is evaluated for treadwear, testing reveals that there is some other factor that influences results in addition to T_g. The Series 2 tests reveal this. These are tests conducted under two extreme conditions: Test 1 under dry-hot conditions, Test 2 under cool, wet conditions; see Table IX for more details. As clearly outlined in the preceding section, the difference in wear rate between Test 1 and Test 2 will be determined by the difference in ambient tire temperature and by the difference in the pavement microtexture for the two tests. Figure 31 is a plot of the Series 2 difference in wear rate (dry-wet) as a function of T_g. A good linear dependence is found with substantial positive differences for low T_g rubbers (or blends); at higher T_g values, the differences are less. In this plot, there are two negative values, a small negative result for a (25/75) SBR/NBR blend and a large negative result for a (25/75) SBR/CIIR (chlorobutyl rubber). For these two, the wet, cool wear rate was greater than the dry, hot. For both of these blends, the reduction of wear due to a negative temperature difference is offset by an increase in wear due to the increase in microtexture that exists for the winter month wet pavement condition. Although the point for the SBR/NBR blend (in the ΔR_w *vs.* T_g plot) does not seriously depart from the good linear regression line for the NR, SBR, and BR blend rubbers, the point for the SBR/CIIR blend is in serious departure.

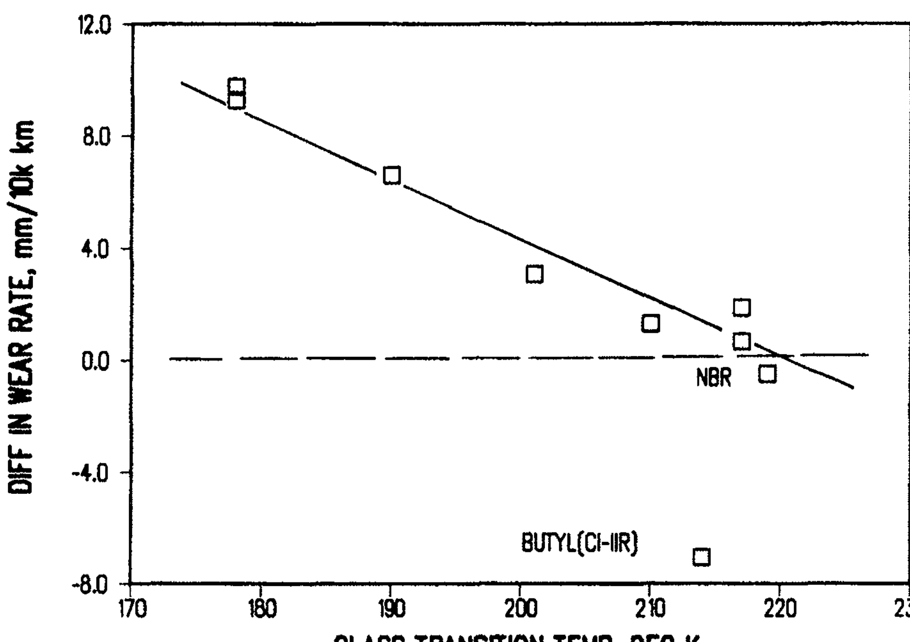

FIG. 31.—Difference in wear rate (dry − wet) *vs.* glass-transition temperature (deg K) for Series 2 compounds, see Table VIII.

In 1984, Schallamach[38] reviewed rubber abrasion and reported on work he had done in 1965 on the abrasion characteristics of various noncrystallizable rubbers. Figure 32 is taken from Schallamach's work and illustrates the temperature dependence of abrasion (open points, dashed line) for unfilled SBR, NBR, butyl (or IIR), and isomerized NR (noncrystallizing NR) using silicon carbide paper (dusted with magnesium oxide) as the countersurface.

At the high-temperature end, all four rubbers show positive temperature coefficients. As temperature is reduced, all four have an inflection point, and at some temperature, a reversal of slope occurs with the onset of a negative temperature-coefficient region. The point of this initial inflection (high to low temperature) is indicated by an arrow below the line. The temperatures of these four inflection points are; 10°, 35°, 50°, and −10°C, respectively, for SBR, NBR, IIR, and isomerized NR.

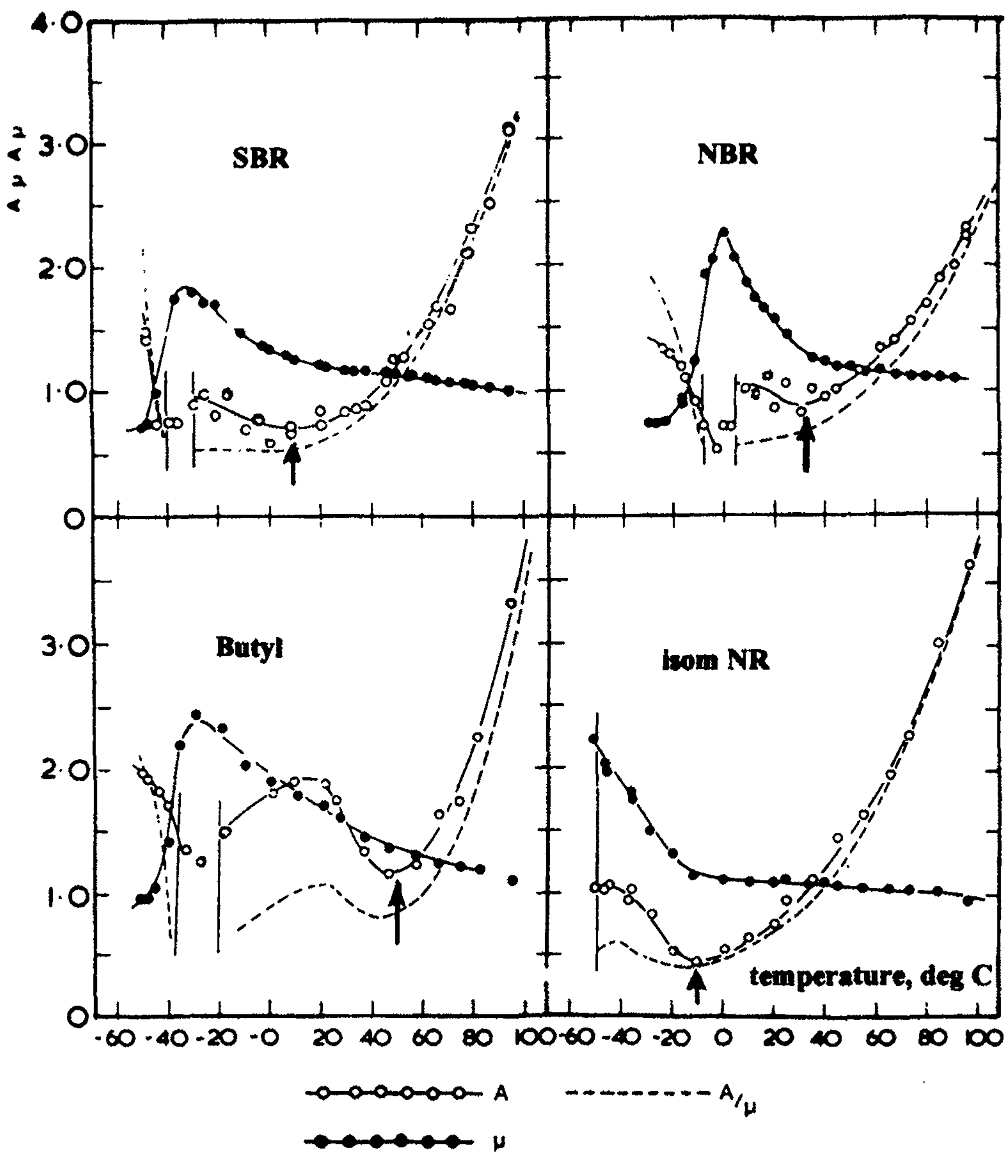

FIG. 32.—Temperature dependence of abrasion for four unfilled rubbers at 1 cm/s sliding speed, from Schallamach[38].

Schallamach observed that at the low temperature end (negative coefficient region), the abraded rubber had abrasion marks or ridges parallel to the sliding direction; whereas, for the high-temperature tests, typical perpendicular "Schallamach patterns" were observed. This change in abrasion pattern was attributed by Schallamach to a change in loss mechanism. At low temperatures, the response was a brittle-plastic response mechanism; at high temperatures, it was a typical highly elastic response.

Figure 33 illustrates a plot of difference in wear rate (dry-wet) for four Series 2 compounds that correspond to the four rubbers of Schallamach's silicon-carbide-carbide-paper abrasion experiments. There is a good linear (negative) dependence showing that a high temperature inflection point corresponds to a large negative difference. This result strongly supports the enhanced micro-texture explanation as the primary cause for the (dry-wet) response shown by the NBR-rich and butyl- or IIR-rich compounds of Series 2. In the case of butyl (IIR) compounds or blends rich in butyl rubber, there is another factor in addition to T_g that influences the treadwear response especially at low temperatures and under conditions of high microtexture. This "X factor" manifests itself in the unique abrasion behavior observed for butyl rubber.

F. REINFORCEMENT—A PRIMARY CONTRIBUTION TO TREADWEAR PERFORMANCE

The most important factor in Table VII is the carbon black. Commercially acceptable tread compounds may be made from a number of different available rubbers, but carbon black is a vitally needed component of any tread compound. Numerous investigations of the effect of carbon-black content and the specific characteristics of the carbon blacks have been conducted over the past four decades. Studebaker[39,40], Dannenberg[41,42], Hess *et al.*[43,44], Jansen and Kraus[45], and numerous others have published on this topic.

Veith and Chirico[46] investigated the influence of four components of the carbon-black-reinforcement system: (1), the morphology or structure of the carbon black, measured by

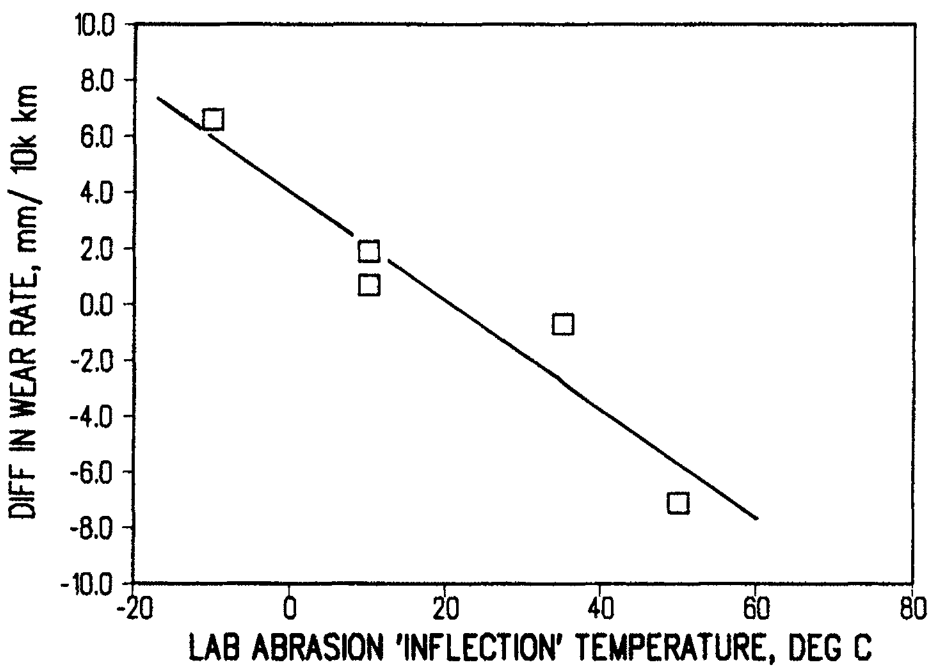

FIG. 33.—Difference in wear rate (dry − wet) for selected Series 2 compounds *vs.* Schallamach "inflection temperature", (lab abrasion on silicon-carbide paper at 1 cm/s).

DBP absorption; (2), the specific surface area of the carbon black, evaluated by electron microscope surface area (EMA); (3), the concentration of carbon black in the compound; and (4), the concentration of process oil. Another important carbon-black variable, the surface activity, was held constant for the work described. A comprehensive study of the influence of these four factors on the rate of treadwear over a very wide range of tire use or severity conditions was conducted.

The influence of each component of the reinforcement system increases as test severity is increased. Carbon blacks with high structure and surface area are substantially superior to blacks with normal structure and surface area at the higher test severities. At the higher severities, increased oil in the compound produces higher wear rates. The rate of wear passes through a minimum as compounds with increased carbon black are tested at any severity level. The carbon-black content of the compound at this minimum wear rate shifts to higher values as the test severity is raised.

Accelerated trailer tests conducted at a series of specific cornering force levels (0.10 to 0.30 g range) show that the treadwear index of typical tread compounds demonstrates cross-overs or inversion of index values. Compounds that show superior wear resistance compared to a reference compound at high severities, frequently show smaller magnitude inferior wear resistance at low severities. Figures 34 and 35 illustrate how the wear index is affected

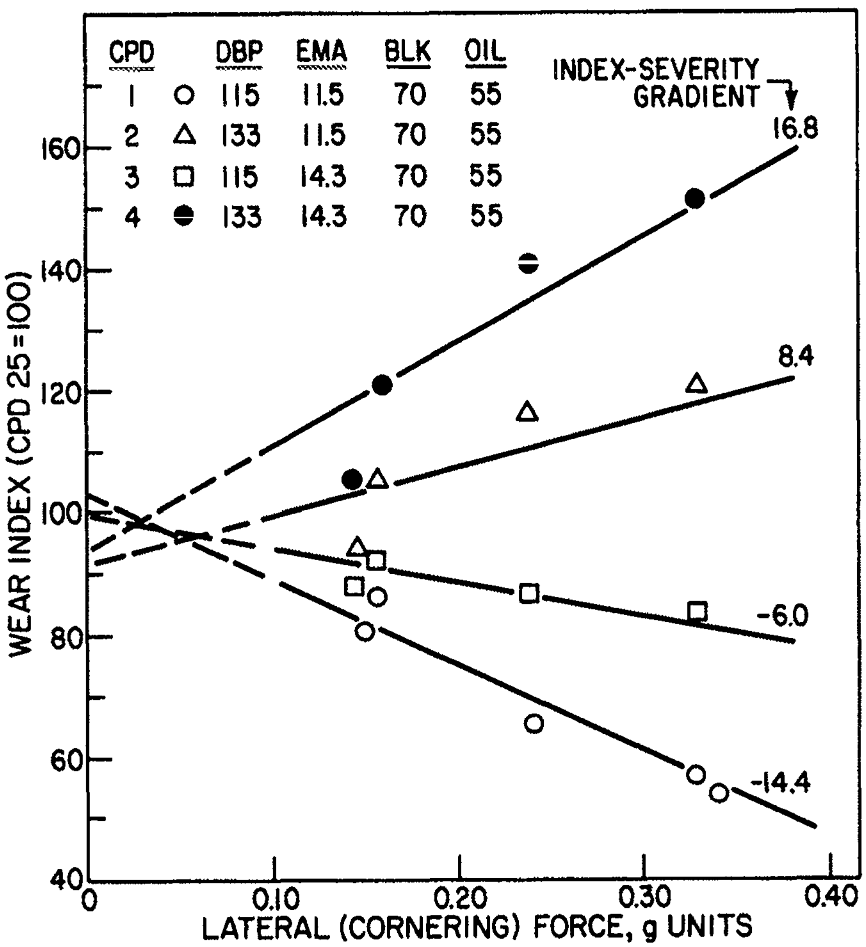

FIG. 34.—Treadwear index *vs.* trailer cornering force for four compounds, see text for Index definition, DBP = indicator of black "structure," EMA = electron microscope surface area of black (inverse particle size indicator); from[41].

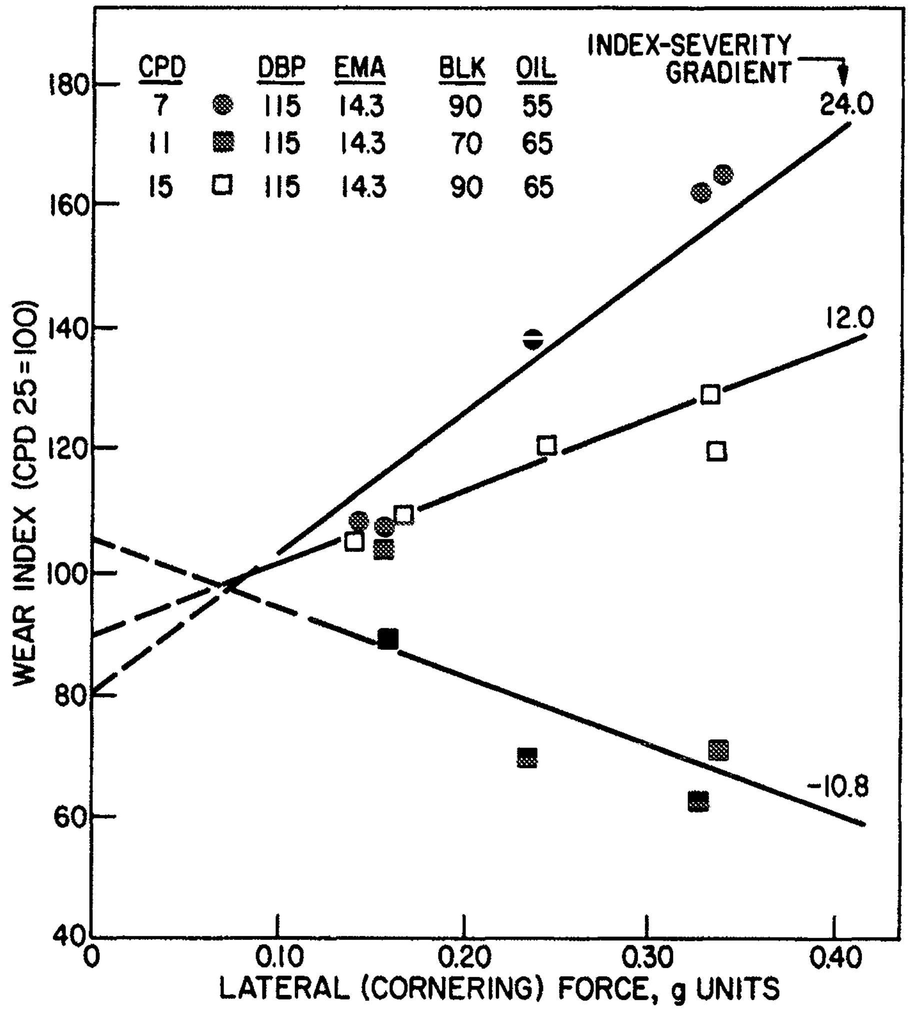

FIG. 35.—Treadwear index *vs.* trailer cornering force for three compounds, same comments as in Fig. 34; from[41].

by the cornering force for the trailer tests. The index is equal to the wear rate of a control tire or compound divided by the wear rate of the candidate tire or compound. The ratio is multiplied by 100.

Both figures show the marked differences in relative wear resistance as the reinforcement varies. In general, the following reinforcement characteristics promote superior high-severity wear resistance: high black levels, low oil levels, high black electron microscope surface area (EMA), and high black dibutyl phthalate absorption (DBP). Compounds with EMA and DBP values that show superior wear resistance at high severities, show a small degree of inferior wear resistance at low severity in the region of 0.05 g. (Compare Compounds 1 and 4 in Figure 34 and compounds 7 and 11 in Figure 35.)

G. TREADWEAR SEVERITY

Although the concept of wear severity has been introduced quite generally in Section I, a more detailed discussion is required at this point. The concept of tire wear severity has

been recognized in a qualitative way from the earliest use of motor vehicles. "Severity" is an omnibus term, which includes numerous conditions that influence wear rate.

It is convenient to classify severity into three categories: (1), tire-force severity (intensity and distribution of tire footprint forces); (2), pavement abrasiveness severity (microtexture of pavement); and (3), weather-temperature severity (tire surface temperatures and interface contaminants, *e.g.*, water). Although the individual magnitudes of the three categories often cannot be assessed, their joint influence can be measured by the wear rate of a reference compound or tire.

One of the first reports on severity was by Baird and Svetlik[47], who found that the wear index of SBR varied from 98 to 216 relative to NR as severity increased. The lowest rating was obtained at a severity characterized by an NR wear rate of 1.05 mm/10 000 km and the highest at an NR wear rate of 6.32 mm/10 000 km. Details on how severity was varied were not given.

Gelsink and Prat[48] reported on tests run over a range of severities and the resulting change in rating of various tread compounds. Many of the high-severity tests were conducted under high-cornering conditions on an automobile race course. Miller, Marlowe, and Ginn[49] demonstrated that for BR tread compounds, ratings varied from 60 to 160 relative to NR as severity was increased. They included cornering wear tests driven on a circular track at various speeds and expressed their results in relation to the lateral g values.

Although the control tire technique is frequently used, its limitations must be realized. The wear rate of a control tire or compound, as a measure of test severity, may give misleading results because it is often not a sufficient indication of the manner in which severity is varied. Tire wear is the product of many specific effects which do not determine wear in a simple additive manner. The single point control is very frequently not able to correct or adjust for complex variations in test conditions. Interpretations of performance should take this into account.

A clean separation of these three components in treadwear testing is not always possible at the present time, although attempts have been made to develop tests that permit such a separation. In the discussion to follow, the term "general severity" will be used to indicate a severity where the three major components occur in unknown proportions.

The distribution of tire wear-out mileages attests to the importance of severity. The ratio of the tread life at the upper end of the distribution (*ca.* 95 percentile) to the tread life at the low end (*ca.* 5 percentile) is of the order of 4 or 5 to one[50–52]. This broad tread life distribution in normal tire use demonstrates the importance of accurately documenting the influence of both particular as well as general severity with respect to tire treadwear performance.

Additional examples of treadwear index variations with changes in general severity are shown in Figures 36, 37 and 38. Figure 36 illustrates how the treadwear index of Compounds 3 and 8 (in the RMA program described in Tables II and III) vary as the general severity changes, given by the wear rate of a reference compound. The four levels of wear rate (about a 3.5 to 1 ratio) were obtained from tests on different aspect ratio generic-type tires (see inset annotation). At the wear rate level of a radial 60 aspect ratio tire, the projected index values of Compound 3 is a few points higher than Compound 8, a slightly superior performance for Compound 3. For the wear rate magnitude of a bias 78-aspect-ratio tire, the projected (and actual) index difference is 20 points, now Compound 8 in a superior performing position.

Wilder, Haws, and Cooper[53] reported on evaluations of carbon blacks over a range of general severity. These results are shown graphically in Figures 37 and 38. Figure 37 shows relationships similar to those cited above; the compound with carbon black N358 is inferior to the control black N330 (which is 100 by definition at all severities) at low general severity (wear rate) but superior at high severity, above about 2 mm/10 000 km wear rate. Figure 38 illustrates analogous behavior for carbon blacks N351 *vs.* N330 and a distinct downward trend in index for N220 *vs.* N330.

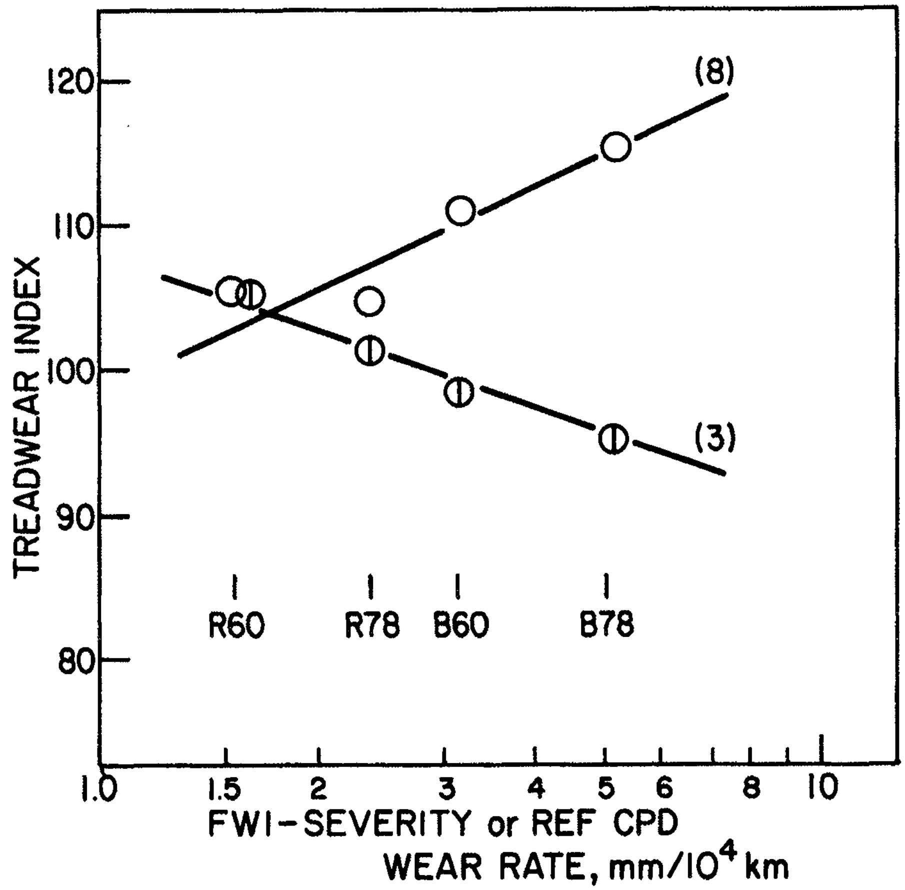

FIG. 36.—Treadwear index *vs.* treadwear severity (reference compound wear rate) for Compounds 3 and 8 of RMA program, see Table III.

Gent *et al.*[26] also reported reversals of laboratory relative abrasion resistance (indexes) for the reinforced (filled) compounds in their test program when the severity of their test conditions were varied from low to high.

H. TREADWEAR *VS.* TEMPERATURE, RAINFALL

Tire temperature is important both for its effect on absolute wear rate and on relative rating of different tread compounds. The tread-footprint surface temperature is the important temperature parameter. This is governed by: (1), the transient surface temperature pulse induced by frictional work in passage through contact; (2), the ambient air and road temperature; and (3), temperature caused by hysteretic heat generated within the tire.

Schallamach[4] has shown that the static tire surface temperature measured within 1 to 2 min after a vehicle is stopped (after previous running) is proportional to the transient temperature in the contact area. For tires tested under constant load, angle, and speed conditions, the static surface temperatures measured in this way follow ambient pavement and air temperatures. Temperature coefficients of tire wear (rate) obtained in this way are pos-

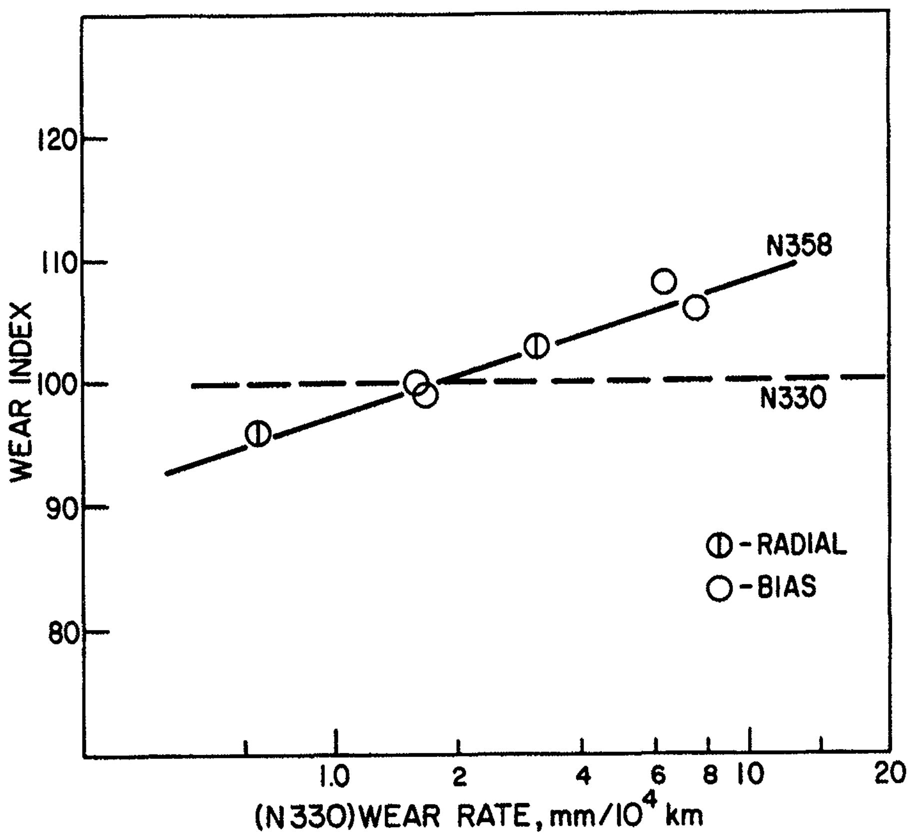

FIG. 37.—Treadwear index *vs.* (severity) reference compound wear rate (N330) for a compound with N358 carbon black, from Wilder, Haws, and Cooper[53].

itive. Table XI shows good agreement on temperature-coefficient data obtained by two investigators.

These data show that for NR and SBR, wear rate increases as temperature increases. It is important to note that Source 2 coefficients[9] were calculated from wear-rate data obtained over a short time span, one to two weeks, on pavements in a state of equilibrium polish or microtexture level. Both sets of data were obtained by the use of instrumented cornering trailers under accelerated wear conditions.

Schallamach's wear rate *vs.* temperature data are illustrated in Figure 39. Although there is considerable scatter, the positive trend of wear rate *vs.* tire surface temperature is unmistakable. Some of the scatter seen in this plot may be explicable by changes in pavement microtexture or abrasiveness as outlined below.

Section V documented the seasonal changes in pavement microtexture. These approximately sine-wave fluctuations are long-wave or low-frequency seasonal variations. Evidence is presented below to show that short term microtexture changes, of a few days duration, also occur due to rainfall and the changes rainfall produces in microtexture due to pavement etching.

Veith[9] discovered this in accelerated trailer treadwear tests. Figure 40 shows depth loss treadwear rate, R_w, normalized to a standard lateral (cornering) force of 500 N, *vs.* tire temperature. The points that generate the solid regression line were wear rates measured on pavement in an equilibrium state of polish or microtexture level, *i.e.*, no rain in the previous week.

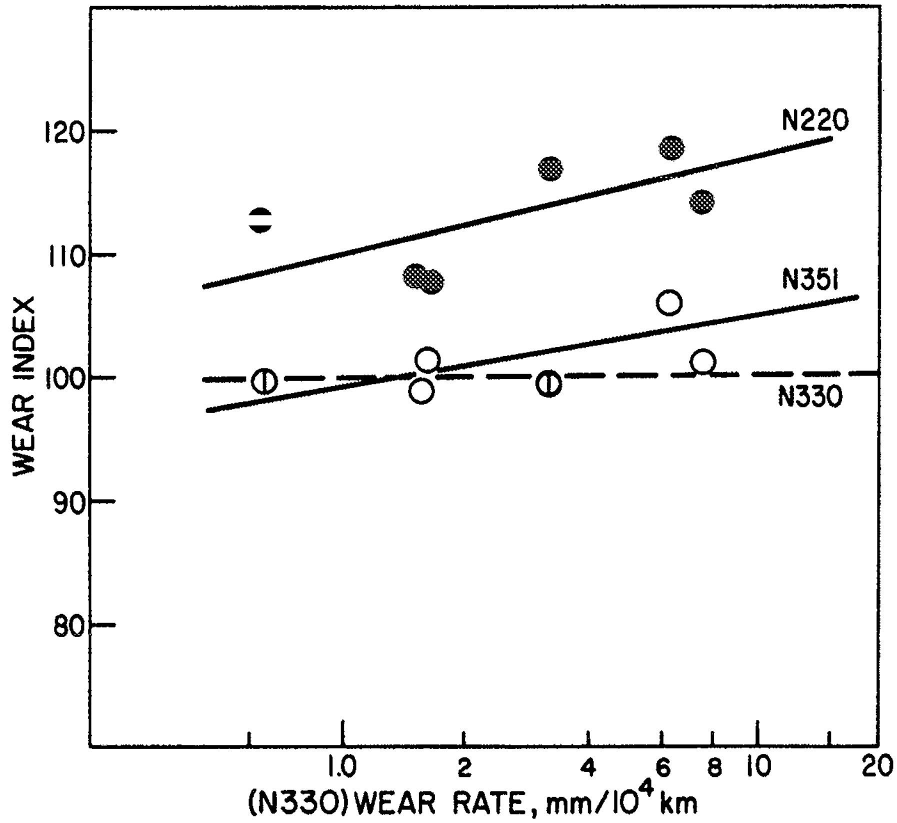

FIG. 38.—Treadwear index *vs.* reference compound wear rate (N330), for compounds with two carbon blacks (N220, N351), from Wilder, Haws, and Cooper[53].

The points represented by R and HR illustrate the influence of changes in pavement microtexture and how this affects wear rate. The R points are for wear rate measured on a dry pavement one day after moderate rainfall, approximately 5 mm during the previous 24 h period. The pavement is a blunt concrete highway with a surface polished by several years of use. The point denoted by HR (heavy rain) was measured after a three-day period where a total of 25 mm of rain fell. These R and HR points show the increased treadwear

TABLE XI

TEMPERATURE COEFFICIENT OF WEAR,[a] α, FOR INDICATED RUBBER

Source of measurement	NR	SBR
1. Schallamach and Grosch[4]	0.04	0.02
2. Veith[9]	0.04	0.02

[a] Values based on $R_w = R_w(50)[1 + \alpha(T - T_0)]$, and $\alpha \times 100$ = % per °C; where: R_w = rate of wear at any temperature, T, and $R_w(50)$ is rate of wear at 50°C, a reference temperature.

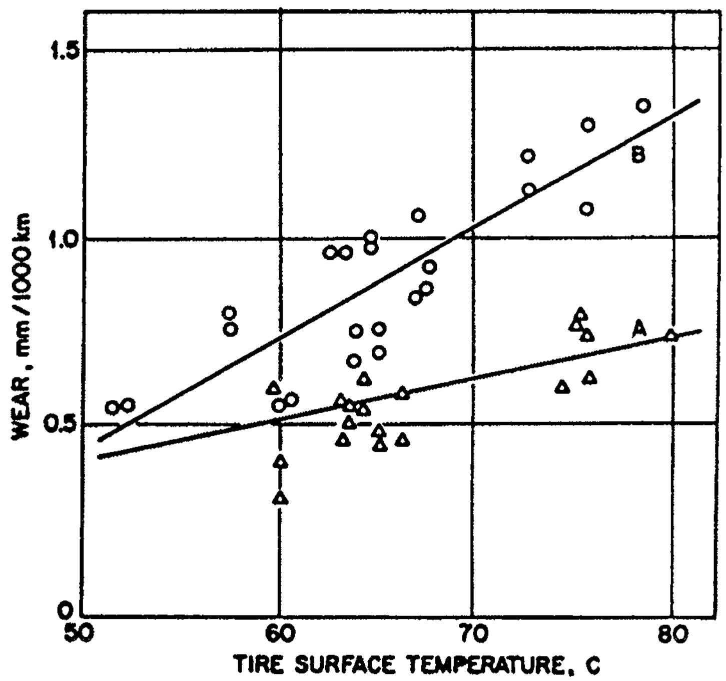

FIG. 39.—Wear rate *vs.* tire surface temperature at 1 deg slip angle; ○ = NR, △ = SBR; from Grosch and Schallamach[4].

compared to the curve, at the particular temperatures in question. Such effects are due to pavement surface etching. This increases pavement abrasiveness as discussed previously in Section V.

These data serve to illustrate the extreme danger in using test fleet or convoy wear rates, winter *vs.* summer, to assess true tire wear temperature coefficients. Unless independent measurements are made to guarantee equivalent pavement microtexture, such seasonal wear-rate changes cannot be used for this purpose. True temperature coefficients of tire wear must be assessed when all other factors that affect wear rate are held constant.

Figure 41 shows additional evidence (another tire set) where previous rainfall again produced increased treadwear for the point marked R. This plot also shows the effectiveness of normalization of wear rates to a standard lateral force (500 N) to correct for intentional variations in slip angle (the 1.5° and 1.75° slip angle points fall on the same line) or for lateral force variations run-to-run. This normalization is accomplished using the square law for wear *vs.* tire force. See Reference 9 for more details.

An example of the reduction in wear rate for an SBR tread compound caused by an actual water film on the road is given in Table XII. The reduction in wear on a harsh high-microtexture pavement, a new concrete highway, is 29%; see part 1 of the table. Note how the tire surface temperature is lowered 15°C by the water. Schallamach suggested that this is the major effect of a water film or wet road in its influence on wear rate, *i.e.*, to lower tire surface temperature. Using a temperature coefficient $\alpha = 0.02$, the dry pavement wear rate for a tire at 34°C, has been estimated in the table. The estimated value is in good agreement with the wet data. The difference (0.76 *vs.* 0.71) may be due to direct lubrication effects. Part 2 of the table gives the magnitude of the HR effect of Figure 40.

I. TREADWEAR AND TREAD COMPOUND DEGRADATION

The fatigue and degradation characteristics of tread compounds are important when treadwear performance is evaluated. Several examples are presented to document this. In

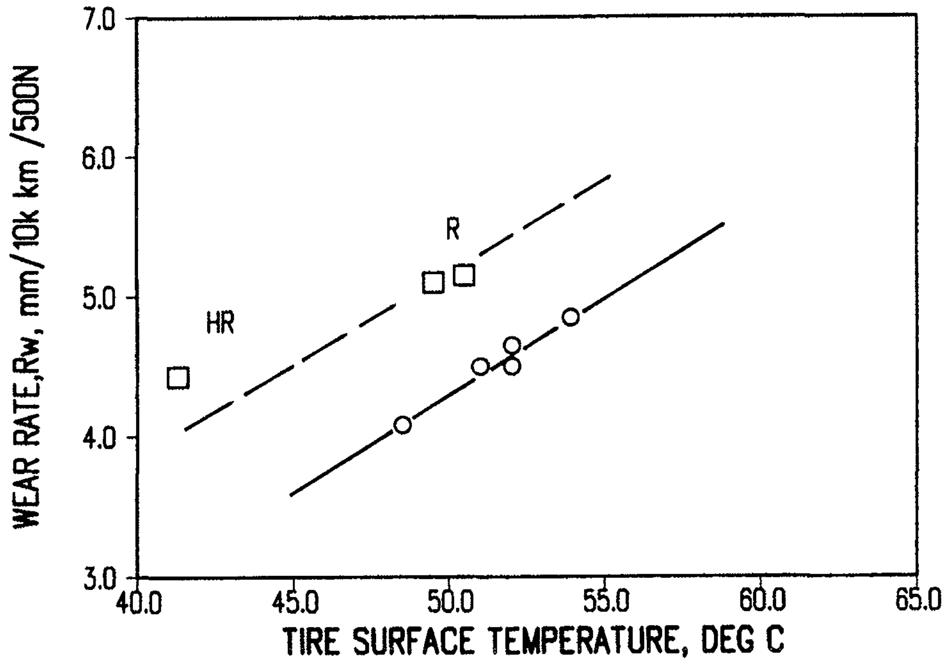

FIG. 40.—Wear rate (R_w) *vs.* tire surface temperature; R_w = depth loss rate normalized to 500 N trailer lateral (cornering) force, see text for R and HR explanation, from Reference 9.

Section VI B one of the Series 1 compounds had a cure system known to produce poor aging vulcanizates, *i.e.*, Compound 10, with 4 phr sulfur and 2 phr DPG. The accelerator DPG in combination with high sulfur, yields high levels of polysulfidic crosslinks.

A review of Figures 20 to 24 shows that the wear rate of Compound 10 is always higher than its normally cured counterpart, Compound 8. This implies that compounds high in polysulfidic crosslinks, suffer a treadwear penalty. Figure 42 shows that the difference in wear rate (Compound 10-Compound 8) is a direct function of the general severity of the testing; the general severity is indicated by the average wear rate of both compounds. Thus, the greater the absolute loss rate, the greater the influence of degradation propensity on rate of wear.

Additional evidence to support the polysulfide crosslink effect for certain loss mechanism conditions is presented in Figure 43. This plot shows that for 1° slip angle trailer tests, the greater the percentage of monosulfide crosslinks, the lower the relative treadwear (0% monosulfide = 1.0). However, when tests are conducted at 2° slip angle, there is no dependence on monosulfide crosslinking. Treadwear at 2° slip angle is of the order of five times the wear rate at 1° slip angle (square law, plus increased temperature). This drastic increase in tire force severity produces an altered mechanism compared to 1° slip. At 2° slip, the frictional work and interface shear forces are intense and indicate a "frictional regime constant property single passage event" path for the loss mechanism per Figure 17.

The exact nature of the degradation mechanism(s) is not totally clear. Oxidation, in addition to straight thermal effects (polysulfide bond scission) are possible. Direct oxidation propensity is important under some treadwear conditions. Figure 44 illustrates the influence of the presence of an antioxidant on a NR tread compound; a 20% reduction in wear rate is realized by the addition of 1.6 phr of the antioxidant.

In addition to the interactive influence of pavement microtexture level, as demonstrated in the discussion of Section VI C on T_g, reinforcement, and seasonal variations, a more direct

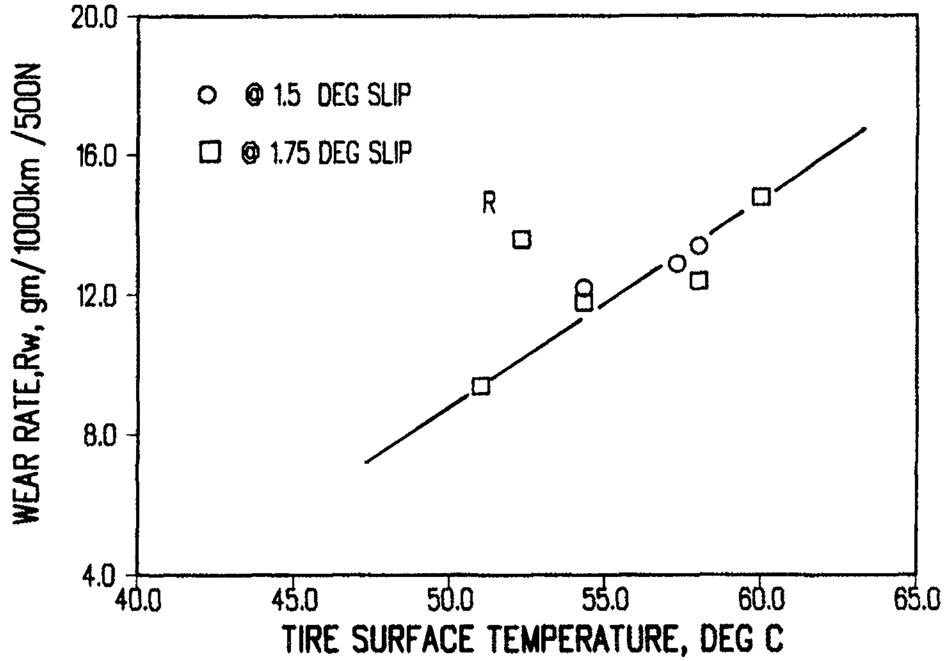

FIG. 41.—Wear rate (R_w) *vs.* tire surface temperature at two slip angles; R_w = mass loss rate normalized to 500 N trailer lateral (cornering) force, see text for R explanation, from Reference 9.

influence has been documented from accelerated trailer testing. Table XIII indicates how microtexture level again changes the loss mechanism for certain rubbers. Two tread compounds were tested: A, a typical SBR/BR (65/35) blend; and B, a blend of SBR and CIIR in a 40/60 ratio. These were tested on two different types of pavement under identical time and ambient-temperature conditions. On the blunt low-microtexture pavement, tread Com-

TABLE XII

EFFECT OF RAINFALL (WET PAVEMENT) ON TREADWEAR

1. Rainfall on pavement (wet)

Pavement condition	Tire temp.	Pavement temp.	Relative wear rate
Dry	49°C	20°C	1.0[b]
Wet	34	18	0.71
Est. dry @ 34°C[a]	(34)	(18–20)	0.76

2. Rainfall effect after pavement is dry

Rain in previous 3-day period	Tire temp.	Relative wear rate
none	56°C	1.0[c]
25 mm	58	1.47

[a] Estimated relative wear rate using temperature coefficient of 2% per °C.
[b] Tests on harsh, high microtexture pavement.
[c] Tests on blunt, smooth (low microtexture) pavement.

pound B, the CIIR-containing compound, wore at a 19% lower rate than A, SBR/BR. On a harsh high-microtexture pavement, Compound B had a 32% greater wear rate compared to A, a reversal in performance.

On the blunt pavement, the predominant loss mechanism is a "frictional regime changing property multiple passage" type. The well documented oxidative degradation resistance of the fully saturated CIIR polymer chains, confers a resistance to degradation, thus its better performance. The SBR/BR compound with less oxidative resistance is inferior.

On harsh pavement the loss mechanism path is a mixture of perhaps a small amount of the frictional regime and a high abrasive-cutting regime content with substantial single passage events occurring in the footprint. Under these conditions, the well documented poorer ultimate strength properties of CIIR compared to the SBR/BR rubber blends, explains the inferior SBR/CIIR blend performance.

Schallamach[6] quotes data obtained by Brodskii[54] on wear tests conducted both in air and nitrogen on monocorundum paper and a blunt knurled metal surface. In air, the wear index of butyl *vs.* oil-extended SBR (as 100) was 58 on the abrasive paper and 83 on the knurled or blunt surface. This is an increase of 25 index points and agrees qualitatively with the tire tests described above. He also showed that the wear rate of butyl is the same in air and nitrogen, illustrating that it is not sensitive to the air degradation effects that occur in SBR and other unsaturated rubbers.

VII. TREADWEAR—MICROSCOPIC EXAMINATION OF WEAR DEBRIS AND WORN TIRE SURFACES

The loss mechanism diagram of Figure 17 says nothing about the actual physical form of the material that leaves the surface of the tire. The exact form of this lost rubber has been a matter of speculation until recently. There are two schools of thought. The first

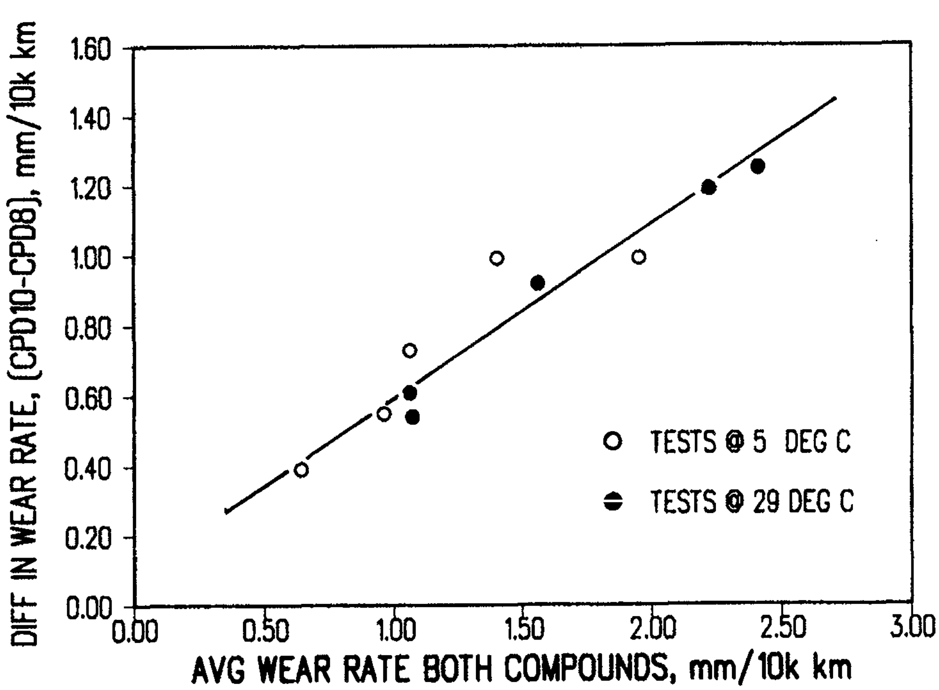

FIG. 42.—Difference in wear rate (Compound 10 − Compound 8) *vs.* average wear rate of both compounds (an indicator of general severity).

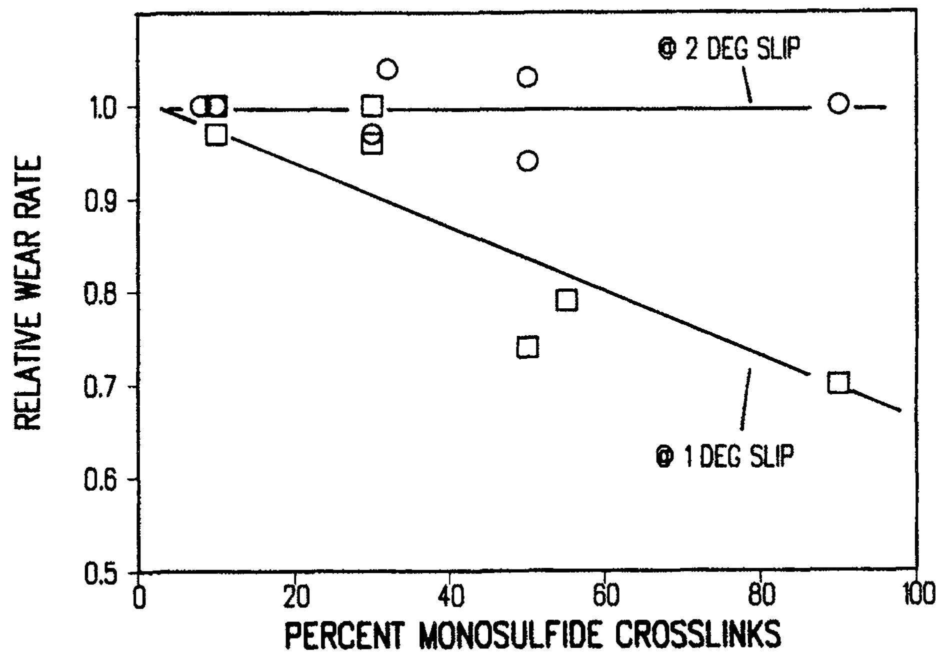

FIG. 43.—Relative wear rate *vs.* percent monosulfide crosslinks at two tire force severities (1 and 2 deg slip angle), from Reference 9.

advocates that the rubber is completely degraded into small molecular fragments that are eliminated in gaseous or volatile form. The second maintains that rubber is removed from the tread surface in particulate form, with a size distribution range depending upon the severity of the tire use.

The most recent and extensive work on the mechanism of the loss of rubber from the tire tread is the work of Dannis[55]. He found no evidence for the loss of rubber by a volatile or gaseous mechanism, instead the loss was attributed to a physical or particulate erosion process. Small particles of rubber are removed from the tread surface because of tangential forces by either a peeling process as previously discussed or an abrasive-cutting action.

Samples of abraded rubber were collected from tires mounted on a vehicle that was driven on public roads. A special vacuum system was employed at the rear of the tire. The size distribution was found to be log-normal; the log of the (equivalent) particle size had a normal distribution. The mean size depended somewhat on vehicle speed and on the road surface characteristics. The particle (equivalent) diameters ranged from 3 to 100 μm with a mean of the order of 12 μm. The collected wear debris had a high nonrubber content, mainly silica or mineral particles that result from the fragmentation of the road aggregate.

Of equal importance, Dannis found that the rubber particles are readily biodegraded by common soil bacteria. Thus, the rubber wear debris particles are airborne for a period of time, settle out of the air on soil (beside the roadways), and with the help of rain, the debris is washed into the soil and biodegraded.

There is ample evidence that the mechano-chemical degradation mechanisms cited in Section V also exist in tire use and testing. Boonstra, Hickman, and Kabaya[56] and Martin and Biddison[57] report that for SBR and SBR/BR blends, a sticky film was present on the surface of tire treads after road testing. This adhered tenaciously, even after (surface) washing with soap and water. Boonstra also observed that the tire surfaces contained substantial amounts of the elements silicon, aluminum, and potassium.

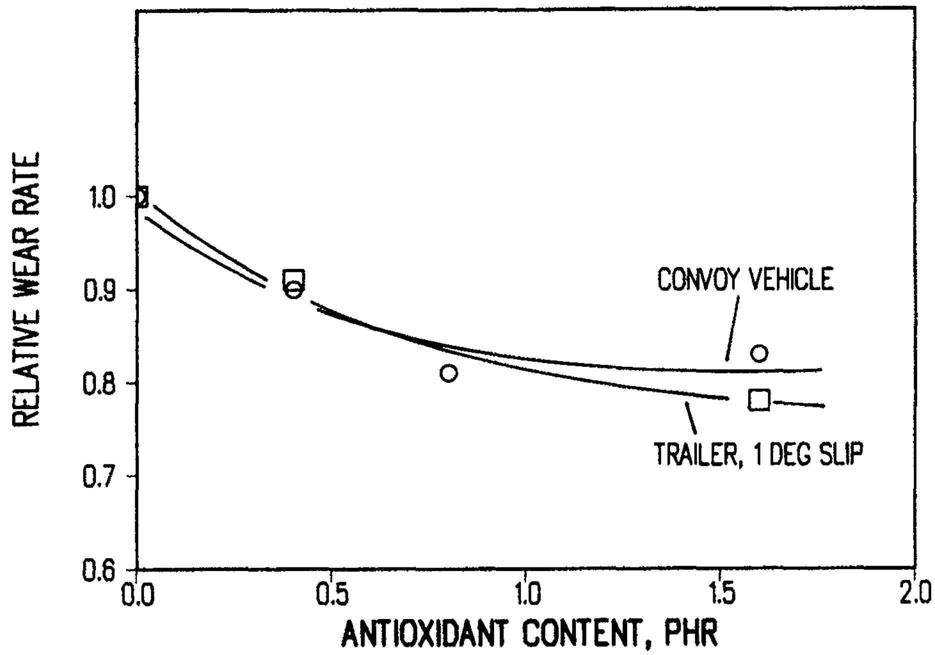

FIG. 44.—Effect of antioxidant content on NR wear rate, blunt (low microtexture) pavement, for two types of testing, trailer and convoy vehicle, from Reference 9.

Smith and Veith[58] also studied tire-tread surfaces after wear testing and also the wear particles that are abraded from tires under high cornering conditions. These were collected by a technique similar to that of Dannis. They examined the particles and the tread surfaces with scanning electron microscopy, energy dispersive x-ray analysis, and transmission electron microscopy (on ultrathin sections).

On the worn tread surface of an SBR compound containing 75 phr N285 carbon black and 45 phr oil, a liquid-like layer composed of an intimate mixture of degraded rubber and road silt was observed on the worn tread surfaces. The thickness of this layer was variable but generally in the micron and submicron region, except where rubber was about to be thrown off as a debris particle. Several collections of rubber debris particles were also examined and found to have the same composition of degraded rubber and road silt that was observed on the tread surface. These observations agree with the results of Boonstra *et al.*[56] with respect to the analysis of road silt materials on tread surfaces.

TABLE XIII

EFFECT OF PAVEMENT TYPE (MICROTEXTURE) ON TREADWEAR OF TWO TREAD COMPOUNDS

Type of test	Pavement	Compound[a]	Relative wear rate
1. Accelerated trailer test	blunt (low microtexture)	A	1.0
		B	0.81
2. Accelerated trailer test	harsh (high micro–macrotexture)	A	1.0
		B	1.32
3. Vehicle convoy testing (APG)	harsh	A	1.0
		B	1.47

[a] Tread Compound A = SBR/BR 65/35; Tread Compound B = SBR/CIIR 40/60.

All of these investigations emphasize the importance of considering tire wear as a three-bodied system: the tread compound, the road surface, and the road silt or detritus. Previous references to the presence of road silt particles on worn tread surfaces implied their incidental nature. This study shows that road silt penetrates into and becomes a part of the substructure of worn tread surfaces. Furthermore, the internal morphology of this substructure is identical to the morphology of the tread debris thrown off the tread surface. Those concerned with elucidating the exact mechanisms of treadwear need to concentrate on this topic.

VIII. EXPLAINING TREADWEAR VARIATION IN UTQG TESTING

Treadwear testing of compounds with varying T_g and with varying levels of reinforcement will produce varying treadwear indexes when tested during different seasons of the year. The current Uniform Tire Quality Grading (UTQG) treadwear testing protocol allows for such year-round testing to assign UTQG grades as mandated by Federal legislation. In this testing, candidate tires are compared to a course monitoring tire (CMT) and a UTQG grade (essentially a treadwear index) is assigned depending on the wear rates of candidate and CMT.

Table XIV lists UTQG grades obtained during three seasonal periods on three tread compounds with varying ratios of SBR/BR, all at a fixed reinforcement level; 72 phr N234 with 40 phr oil. Although there are no reversals of relative standing of these three tread compounds over the range of test temperatures (5, 16, and 29°C), the difference in treadwear performance changes rather dramatically. This is best seen in a plot of UTQG grade *vs.* test temperature as illustrated in Figure 45.

At 5°C (winter performance) there are substantial differences among all three; at 29°C (summer performance) the three compounds are very similar in their performance. The difference between Compounds 1 and 2 is probably well within the test-to-test error component and would be declared as nonsignificant. Note that the two BR-containing compounds have negative slopes, UTQG grade *vs.* temperature, while the all-SBR compound has a slight positive slope. The tread composition of the CMT tires used for this testing is important; it is the reference compound that determines the value of these slopes. The CMT tire tread compound at the time of this testing was a 90/10 blend of SBR/BR, with a weighted average T_g of 212°K.

There has been considerable discussion and controversy in the technical and trade literature concerning random test error and its influence on UTQG grades. Table XIV and Figure 45 clearly show that year-round variations in UTQG grade will be obtained that are due to intrinsic changes in compound treadwear response, season-to-season. For any in-depth assessment and evaluation of the UTQG test and its relevance to real-world treadwear

TABLE XIV

VARIATION IN UTQG GRADES ON SEASONAL BASIS

		UTQG grade[a] @ indicated test temperature			
Compound[b]	T_g	5°C	16°C	29°C	Slope[c]
1. SBR/BR 50/50	194 deg K	429	374	322	−4.5
2. SBR/BR 75/25	205	337	322	305	−1.3
3. SBR 100	217	234	252	272	1.6

[a] Course Monitoring Tire for this testing contained SBR/BR 90/10, T_g = 212°K.
[b] All compounds contain 72 N234 black and 40 oil.
[c] Slope of plot: UTQG grade *vs.* test temperature (°C).

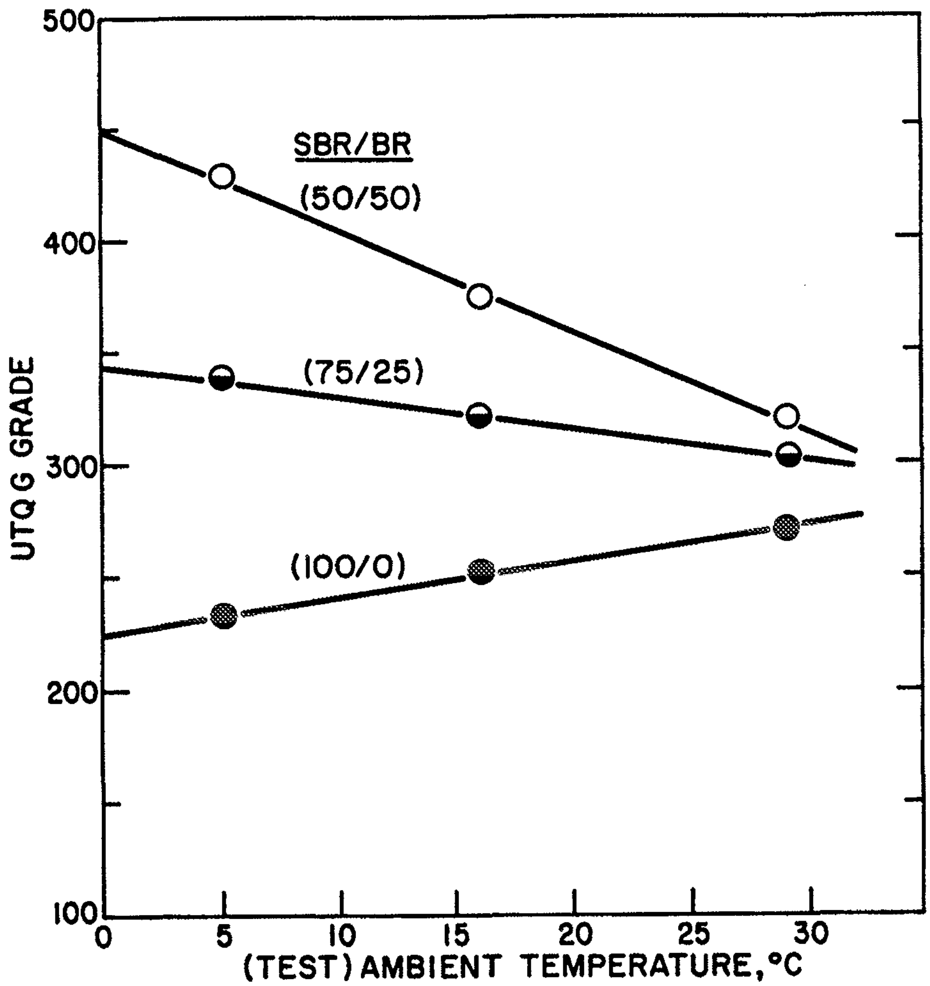

FIG. 45.—UTQG grade *vs.* ambient treadwear test temperature.

performance, such intrinsic compound treadwear response variations must be accounted for and not attributed to unknown causes or referred to as experimental error.

IX. CONCLUSIONS

For any specific tire use condition, treadwear performance is influenced by three main factor categories: (1), tire construction; (2), tread materials; and (3), environmental and vehicle use conditions.

Tire construction factors are—generic type (bias, belted-bias, radial), tread pattern groove void level, and geometric shape, *i.e.*, aspect ratio. The relative importance of nominal variations in each of these factors for treadwear performance is 100, 46, and 39, respectively. Performance improves for a change from bias to radial; high to low groove void; and high to low aspect ratio. The combined influence of generic type, aspect ratio, and other internal construction features (*e.g.*, belt stiffness) can be described by one parameter, the ratio of the treadband edgewise bending stiffness, K_B^o and the carcass (spring) stiffness, K_c. Treadlife is a direct linear function of this ratio.

Treadwear compound or material performance is a function of the rubber glass-transition temperature (weighted avg. for blends), and the degree of reinforcement which is dictated by the carbon-black structure, surface area, and surface chemistry, in addition to the amount of black in the compound. The effect of each of these is a complex function of (i), the severity of tire use (*e.g.*, cornering intensities) and (ii), the long term (seasonal) and short term (daily) environmental factors of pavement microtexture (0.01 mm scale) and ambient temperature. Precipitation directly influences microtexture level through a chemical etching of the pavement aggregate particles. Increased T_g and carbon-black reinforcement can improve or degrade treadwear performance depending on the external factors of pavement microtexture and ambient temperature and also on the general severity of tire use. Treadwear performance is also influenced by the degradation characteristics of the tread compound. Degradation propensity is influenced by crosslink structure and general susceptibility to oxidation. High wear rates are encountered for compounds cured with high-sulfur cure systems (high crosslink polysulfide content) and with low levels of antioxidant.

Substantial evidence exists to support a "two-mechanism" theory of rubber abrasion. Mechanism 1 is predominant when the rubber tread element experiences highly elastic surface deformations induced by frictional contact with the pavement asperities. Rubber particles are removed by a tear-tensile rupture process. Mechanism 2 is predominant when the rubber experiences a plastic or rigid body type of contact with the pavement asperities. This contact exists on a smaller scale (reduced deformation domain) and particles are removed by an abrasive-cutting action. Mechanism 1 is called "E-Wear"; Mechanism 2 is called "P-Wear". E-wear is favored by high temperatures, low microtexture pavements, soft (low T_g) compounds with low reinforcement levels. P-wear is favored by high microtexture, low ambient temperatures, hard (high T_g) compounds with high levels of reinforcement.

The confusing treadwear performance frequently encountered for compounds—when tested at different locations, at different times, with substantial treadwear index changes, and outright reversals—can be rationally explained on the basis of a shift of the predominant mechanism. These shifts are due to changes in the environmental factors and tire-use severity as tires are tested at different locations over varying seasonal periods. Microtexture follows a seasonal cyclic pattern; high in winter and low in summer. Ambient temperature follows an opposite cyclic pattern. Short term changes (daily) in both microtexture and temperature occur within the long-term seasonal periods. These changes have to be accommodated in interpreting treadwear performance.

X. ACKNOWLEDGMENTS

I thank the Uniroyal–Goodrich Tire Company for providing generous support to me over the years of my research effort on tire treadwear and for the approval to publish this review.

XI. REFERENCES

[1] V. E. Gough, *Wear* **2**, 107 (1958/59).
[2] V. E. Gough, *SAE Tech. Paper* 667A Detroit, MI (1963).
[3] V. E. Gough, Paper presented at Deutsche Kautchuk Gesell. Meeting, June, 1965.
[4] K. A. Grosch and A. Schallamach, *Wear* **4**, 356 (1961).
[5] A. Schallamach and D. M. Turner, *Wear* **3**, 1 (1960).
[6] A. Schallamach, RUBBER CHEM. TECHNOL. **41**, 209 (1968).
[7] A. G. Veith and K. L. Oblizajek, [Four papers], *Tire Sci. Technol.* **14**, 201-291 (1986).
[8] J. D. Walter, G. N. Avgeropoulos, M. L. Janssen, and G. R. Potts, *Tire Sci. Technol.* **1**, 210 (1973).
[9] A. G. Veith, RUBBER CHEM. TECHNOL. **46**, 801, 821 (1973).
[10] R. W. Topping, Private Communication.
[11] W. K. Shepherd, *ASTM Spec. Tech. Publ.* **n. 229**, (1986).
[12] A. Kondo and F. C. Brenner, RUBBER CHEM. TECHNOL. **44**, 960 (1971).
[13] A. G. Veith, See Lecture Notes "Tire Mechanics" Course Univ. of Akron; Part II, "Traction and Treadwear".
[14] A. G. Veith, *Tire Sci. Technol.* **14**, 139 (1986).
[15] B. Briscoe, *Tribol. Int.* **14**, 231 (1981).
[16] D. F. Moore and W. Geyer, *Wear* **22**, 113 (1972).

[17] D. F. Moore, "Friction and Lubrication of Elastomers," Pergammon Press, New York, 1972.
[18] D. Tabor, "Advances in Polymer Friction," Pergammon Press, New York, 1972.
[19] A. R. Savkoor, *Wear* **8**, 222 (1967).
[20] D. Tabor and K. Ludema, *Wear* **9**, 329 (1966).
[21] H. W. Kummer, *Eng. Res. Bull. (P. State Univ. Coll. Eng.)* **B94**, (1966).
[22] A. Schallamach, *Wear* **17**, 301 (1971).
[23] A. Kendall, *Wear* **33**, 351 (1975).
[24] A. D. Roberts and A. G. Thomas, *Wear* **33**, 45 (1975).
[25] A. D. Roberts and S. A. Jackson, *Nature* **257**, 118 (1975).
[26] A. N. Gent and C. T. Pulford, *J. Appl. Polym. Sci.* **28**, 943 (1983).
[27] D. Champ, E. Southern, and A. G. Thomas, *Am. Chem. Soc., Div. Org. Coat. Plast. Chem. Pap.* **34**(1), 237 (1974).
[28] S. W. Zhang, *Tribology Int.* **22**, 142 (1989).
[29] A. R. Williams, T. Holmes, and G. Lees, *SAE Tech. Paper* 720162, Detroit (1972).
[30] R. Bond, G. Lees, and A. R. Williams, "The Physics of Tire Traction," Plenum Press, Elmsford, NY, 1974, p. 339.
[31] H. W. Kummer, RUBBER CHEM. TECHNOL. **41**, 895 (1968).
[32] E. A. Whitehurst and J. B. Neuhardt, *ASTM Spec. Tech. Publ.* **n. 229**, 1986.
[33] R. W. Lowne, RUBBER CHEM. TECHNOL. **44**, 1159 (1971).
[34] R. N. Kienle, E. Dizon, T. Brett, and C. Eckert, RUBBER CHEM. TECHNOL. **44**, 996 (1971).
[35] A. G. Veith, *Polym. Test.* **7**, 177 (1987).
[36] J. K. Lancaster, *Wear* **14**, 223 (1969).
[37] D. Bulgin and M. H. Walters, *Proc. Int. Rubber Conf., 5th*, Brighton, 1967 (1968).
[38] A. Schallamach, *Prog. Rubber Technol.* **46**, 107 (1984).
[39] M. L. Studebaker, RUBBER CHEM. TECHNOL. **41**, 373 (1968).
[40] M. L. Studebaker, "Reinforcement of Elastomers," Interscience, NY, 1965, (ch. 12).
[41] E. M. Dannenberg, et al., *Rubber World, 131*, 1955, *Rubber Age NY*, **85**(3), 431 (1959).
[42] E. M. Dannenberg, RUBBER CHEM. TECHNOL. **59**, 497 (1986).
[43] W. M. Hess, E. Micek, and F. Lyon, RUBBER CHEM. TECHNOL. **41**, 1271 (1968).
[44] W. M. Hess, L. Ban, and L. Papazian, RUBBER CHEM. TECHNOL. **47**, 858 (1974).
[45] J. Jansen and G. Kraus, *J. Elasto. Plast.* **6**, 142 (1974).
[46] A. G. Veith and C. E. Chirico, RUBBER CHEM. TECHNOL. **52**, 748 (1979).
[47] J. Baird and F. Svetlik, RUBBER CHEM. TECHNOL. **26**, 731 (1953).
[48] H. A. Gelsink and L. Prat, RUBBER CHEM. TECHNOL. **31**, 166 (1958).
[49] R. Miller, R. Marlowe, and J. Ginn, *Rubber Plast. Age* **42**, 968 (1961).
[50] T. French and V. Gough, *Int. Tech. Congr. Motor Ind.*, 5th, Munich, Sept. 1954; *Automobiltech. Zeits.* **57**, 91 (1955).
[51] *Mod. Tire Dealer* **51**(6), 130 (1970).
[52] R. H. Snyder, *Tire Sci. Technol.* **1**, 202 (1973).
[53] C. R. Wilder, J. R. Haws, and W. T. Cooper, RUBBER CHEM. TECHNOL. **54**, 427 (1981).
[54] G. I. Brodski, *Sov. Rubber Technol.* **19**, 22 (1960).
[55] M. L. Dannis, RUBBER CHEM. TECHNOL. **47**, 1011 (1974).
[56] B. Boonstra, F. Heckman, and A. Kabaya, *Rubber Age* **104**(4), 33 (1972).
[57] F. Martin and P. Middison, RUBBER CHEM. TECHNOL. **46**, 586 (1973).
[58] R. W. Smith and A. G. Veith, RUBBER CHEM. TECHNOL. **55**, 469 (1982).

SHORT REVIEWS

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Though broadly complete in authoritative coverage of a topic, a Short Review is not exhaustive in detail. It is a state-of-the-art summary by an author currently active in the field. Its bibliography should at least serve as a starting point for a more exhaustive search. A Short Review emphasizes recent developments in the field but is not limited to them.

A Short Review is of such length as to be read and comprehended in one sitting. It has the same authoritative standard as regular review articles. Stress is placed on rapid publication, with the bibliography thus containing more recent citations.

Suggestions for further topics and authors of Short Reviews will be welcomed. They should be directed to the Chairman of the Rubber Reviews Editorial Board (see title page of this issue).

Three Short Reviews are on the pages which follow.

EXHIBIT B

"Agenda for Examiner Interview"
Submitted May 18, 2011
for Telephone Interview on May 19, 2011

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Agenda for Examiner Interview

Application No. 10/584,798
Attorney Docket No. 07040.0262
Examiner Justin Fischer, (571) 272-1215; Fax (571) 273-1215
Representative: Ben Bailey, (404) 653-6435
Date: Thursday, May 19, 2011
Time: 9:30am EST

Applicants would like to discuss the claim rejections contained in the final Office Action dated September 20, 2010 in light of the enclosed reference, which was recently uncovered by Applicants. In particular, Applicants would like to discuss a couple of the Examiner's assertions based on the Fukuda reference.

Independent claim 35 recites, in part:

> A pneumatic tire comprising . . . a tread band[,] the tread band comprising:
>
> i) at least one radially extending first sector substantially of a first elastomeric material;
>
> ii) a plurality of radially extending second sectors positioned at axially opposite sides of said at least one first sector and substantially of a second elastomeric material;
>
> iii) at least one longitudinal groove formed in said at least one first sector and extending substantially for the entire circumferential development of the tread band, the at least one longitudinal groove defining a cross section;
>
> wherein said first elastomeric material has a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of said second elastomeric material,
>
> wherein the modulus of elasticity under compression at 23°C of said first elastomeric material is 20 to 80 MPa, and
>
> wherein a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70 such that the cross section of

> the at least one longitudinal groove remains substantially constant when a radially outer surface of the tread band is in contact with the ground.

Independent claims 53, 71, 85, 96, and 108, although of different scope, recite similar elements.

In the Office Action, the Examiner rejected independent claim 35 based, in part, on JP 53080602 ("Fukuda"). Specifically, the Examiner relies on Fukuda as disclosing "said first elastomeric material has a modulus of elasticity under compression at 23°C greater than the modulus of elasticity under compression at 23°C of said second elastomeric material," and "a ratio between an IRHD hardness at 23°C of the first elastomeric material and an IRHD hardness at 23°C of the second elastomeric material is 1.15 to 2.70."

The Examiner concedes that Fukuda is silent with respect to modulus of elasticity and hardness values. However, the Examiner maintains that Fukuda implicitly teaches these elements based on its disclosure of a tread band comprising two elastomeric materials, one exhibiting a higher wear resistance than the other. According to the Examiner, a higher wear resistance necessarily implies both a higher modulus of elasticity and a higher hardness. Office Action at 2-3, 12. It is with these assertions that Applicants respectfully disagree with the Examiner.

In support of Applicants position that a higher wear resistance does not, in fact, necessarily imply a higher modulus of elasticity or a higher hardness, Applicants submit the enclosed reference, "A Review of Important Factors Affecting Treadwear," by Alan G. Veith. As the title suggests, this reference reports a detailed study of the mechanisms and factors governing treadwear and illustrates which characteristics are important and which are not.

More particularly, the reference demonstrates the following:

- wear resistance appears to be entirely unrelated to the hardness of the rubber materials, as the parameter hardness is never mentioned;
- wear resistance appears to be unrelated to the elastic modulus E' of the rubber materials, as the parameter chosen in the paper to reflect the degree of reinforcement (which has an impact on treadwear) is in fact the loss modulus E" (*see* page 604, last paragraph);
- as discussed in the paper, "no claim may be made that treadwear is solely related to loss modulus" (*see* page 605, first paragraph);
- treadwear material performance is a function of the rubber glass-transition temperature Tg and the degree of reinforcement which is dictated by the carbon black structure, surface area, and surface chemistry, in addition to the amount of carbon black in the compound; the effect of each of these is a complex function of: (i) the severity of tire use and (ii) the long term and short term environmental factors of pavement microtexture and ambient temperature (*see* page 657, lines 1-7);
- increased Tg and carbon black reinforcement can improve or degrade treadwear performance depending on the external factors of pavement microtexture and ambient temperature and also on general severity of tire use (*see* page 657, lines 8-10);
- treadwear performance is also influenced by the degradation characteristics of the tread compound which is influenced in turn by crosslink structure and general susceptibility to oxidation (*see* page 657, lines 11-13);
- the so-called P-wear mechanism is favored by a high level of reinforcement, (i.e. a high level of the loss modulus E") abrasion resistance being attributed to low modulus (*see* page 632, last paragraph, page 636, comments to plots 1-3, page 657, lines 23-24);
- a high degree of reinforcement (i.e. a high level of the loss modulus E") is not necessarily good, since modulus is increased along with an increase in strength and this increase may outbalance the increased reinforcement strength for a net increase in abrasion (*see* page 633, first paragraph);
- P-wear is favored by hard compounds (high black level that is with high level of the loss modulus E") (*see* page 635, first paragraph).

Thus, this paper demonstrates that: (1) a higher wear resistance can be entirely unrelated to both the elastic modulus E' and to the hardness of the rubber materials; and (2) hardness can have a detrimental effect on treadwear.

In light of the above comments and the enclosed reference, Applicants respectfully request that the Examiner reconsider the assumptions made in the final Office Action based on Fukuda.

Respectfully submitted,

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/Benjamin D. Bailey/

Dated: May 18, 2011

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X. Related Proceedings Appendix

None